Report No. CG-D-04-92

BUOY TECHNOLOGY SURVEY
USCG BUOY DEVELOPMENT REVIEW

John C. Daidola
Nedret S. Basar
Fontain M. Johnson

M. ROSENBLATT & SON, INC.
and
Richard T. Walker

U.S. COAST GUARD RESEARCH AND DEVELOPMENT CENTER
AVERY POINT, GROTON, CONNECTICUT 06340-6096

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SAMUEL F. POWEL, III
Technical Director
United States Coast Guard
Research & Development Center
1082 Shennecossett Road
Groton, CT 06340-6096

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16. Abstract

The research and development efforts by the U.S. Coast Guard since 1962 on floating aids to navigation (ATON) buoys are reviewed. Interviews are conducted with USCG ATON personnel at the headquarters, the R & D Center, the five district (oan) offices, buoy tender crews, industrial facilities and with a limited number of buoy manufacturers in the United States.

The USCG buoy development since 1962 is established in the form of twenty seven Project Summaries and supplemented with a comprehensive "Buoy Technology Bibliography" and a compilation of "Buoy Technology Abstracts" for most of the buoy hull related references in the Bibliography. The latter two compilations are input into a USCG computer database.

On the basis of data obtained from personnel interviews and from the literature reviews, the status of current USCG buoy technology is established and suggestions for further R & D are recorded. This report is the result of Task A of the "Buoy Technology Survey". In Task C of the project, these R & D suggestions are to be evaluated to arrive at recommendations for future buoy development.

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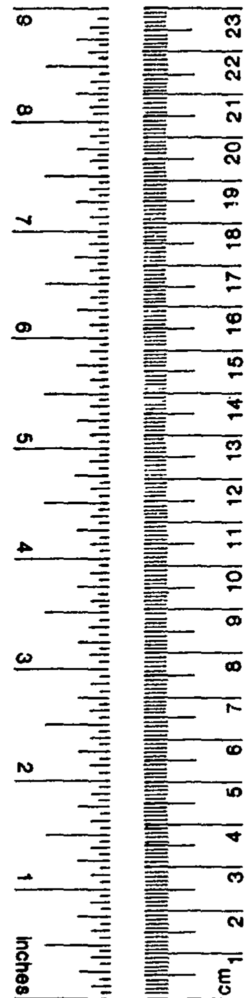
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

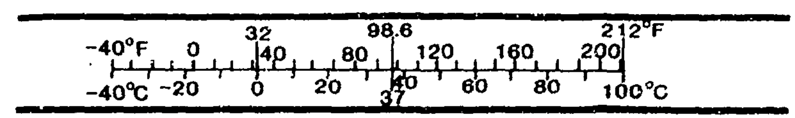
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures. Price $2.25. SD Catalog No. C13.10 286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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LIST OF ABBREVIATIONS

AB	Articulated Beacon
ABS	Acrylonitrile-Butadiene-Styrene
ALERP	Aluminum Lighted Emergency Reinforced Plastic
ANBESS	Aids to Navigation Buoy Environmental Sensing System
ANT	Aid to Navigation Team
ATON	Aids to Navigation
BTIS	Buoy Technolgy Information System
BTS	Buoy Technology Survey
CALM	Chain Anchor Leg Mooring
CAN	(Name given to cylindrically shaped buoy)
CANUN	(Name given a buoy with interchangeable CAN and NUN shapes)
DTIC	Defense Technical Information Center
ECV	Office of Engineering, Logistics, and Development
ELB	Exposed Location Buoy
FRP	Fiber Reinforced Plastic
GRP	Glass Reinforced Plastic
IALA	International Association of Lighthouse Authorities
IEEE	Institute of Electrical and Electronic Engineers
LNB	Large Navigation Buoy
LORAN	Long Range Aids To Navigation
MTS	Marine Technology Society
NBS	New Buoy Systems
NDBC	National Data Buoy Center
NSR	Office of Navigation and Waterway Safety (USCG)
NTIS	National Technical Information Service
NUN	(Name given a conically shaped buoy)
POD	Probability of Detection
POR	Probability of Recognition
PVC	Polyvinyl Chloride
R&D	Research and Development
R&DC	Research & Development Center
RMS	Root Mean Square
SALM	Single Anchor Leg Mooring
SANDS	Simplified Aids to Navigation Data System

LIST OF ABBREVIATIONS (cont'd)

SNAME	Society of Naval Architects and Marine Engineers
SOW	Statement of Work
SRA	Short Range Aids
STATO	(Name given a specific type of anchor)
SWATH	Small Waterplane Area Twin Hull
TBTO	Tributyltin Oxide
TICWAN	(Name given a small ATON servicing boat)
TOR	Tentative Operating Requirements
USCG	United States Coast Guard
WAMS	Waterway Analysis and Management Systems
WATG	Wave Activated Turbine Generator
WGDB	Wine Glass Discrepancy Buoy
WHOI	Woods Hole Oceanographic Institution

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1.0 INTRODUCTION

1.1 Background

The Marine Aids to Navigation (ATON) System of the United States is an extensive and comprehensive array of devices external to a vessel. It is intended to assist a navigator in determining his position, plotting a safe course, identifying obstructions to navigation, and to promote safe and economic movement of commercial traffic. The United States Coast Guard (USCG) operates and administers this system which services the needs of and benefits the maritime commerce, the general boating public and the armed forces. A subgroup of this system is the Short Range Aids (SRA) to navigation system including navigational devices within visual, audible, radar or low power radiobeacon range. The current project, Buoy Technology Survey, as part of USCG's "New Buoy Systems" development, is concerned with the buoy platform of the floating aids segment of the SRA system. The buoy platform is defined as consisting of the hull, mast and counterweight.

The objective of this project is the buoy platform and excludes the direct and detailed consideration of such related matters as mooring systems, signalling devices, and the much broader consideration of SRA type, arrangement and effectiveness. The fact that the mooring system and signalling devices are sometimes integrated with the platform has resulted in an indirect consideration of these features as will be evident in the material that follows. However, the larger question of type, arrangement and effectiveness of the complete system could not be addressed in detail within the constraints of this project. In an overall evaluation of the SRA system, such considerations should also be addressed. The USCG's Waterway Analysis and Management System (WAMS) is considering this matter as a separate investigation.

With this said, it is appropriate to move ahead with the subject of this study, the buoy platform. The evolution of buoys as aids to navigation is an ongoing process. There are perceived possibilities for the improvement of buoys both through evolution and innovation. The USCG has identified a number of specific problems that need to be addressed.

In order to research the potential technologies which could advance the state of the art in buoys as aids to navigation, the USCG has initiated the "New Buoy Systems" project. The Buoy Technology Survey is the first step in this new project with the purpose of conducting an overall technology assessment of buoy systems. This will be accomplished by the following three tasks:

TASK A - Review of the research and development efforts by the USCG on aid to navigation buoy development since 1962.

TASK B - World-wide survey of existing buoy technology and compilation of survey data in a computer database.

TASK C - Formulation of recommendations for the development of improved aid to navigation buoys for the USCG.

This report is concerned with TASK A only. M. Rosenblatt & Son, Inc. has reviewed all available technical documents and literature relating to SRA buoy design or development since 1962 and has interviewed USCG management personnel involved with buoy designs, maintenance, and development as well as a number

of U.S. based buoy manufacturers. The objectives of these reviews and interviews include as a primary goal, capturing and documenting the history of USCG buoy development since 1962 by filling in the gaps in findings of literature reviews in topics such as the cataloging of information, identification of problem areas, advances in related technology, changes in operational practices, and International Association of Lighthouse Authorities (IALA) conformance requirements.

During TASK B, surveys will be conducted of foreign country navigation authorities responsible for buoys and the manufacturers of buoys, both domestic and foreign, and a computer database of the information collected in this project will then be developed. The objectives of the task will include the screening of worldwide engineering and technical information on buoy systems, approaches to problem solving (particularly those that have been identified by the USCG), and development of a computer database for use by the USCG which is both relational and retrievable. The completed program will be developed on a USCG supplied computer and software, and will then be installed at the USCG R&D Center and at the USCG Headquarters (G-ECV and G-NSR).

The principal objective of TASK C is to evaluate buoy technologies in order to identify those that show the most promise for improving the SRA system. This will be accomplished by carrying out a matrix analysis of the technologies to rank them in accordance with their benefits as judged by three measures of merit: average annualized cost, operational effectiveness, and handling safety.

1.2 Historical Perspective

Today buoys are used for many purposes besides aids to navigation, including use as platforms for scientific or engineering investigations, for gathering synoptic data, and supporting ocean operations such as oil tanker loading/unloading at production sites. However, without a doubt, the first concentrated use of buoys was as aids to navigation. Over the years, in the United States, the SRA system has grown and is now prevalent in most all U.S. waterways including coastal areas, inland waterways, harbors, harbor entrances, and rivers. Similar but smaller systems exist in other countries.

As stated above, the process of buoy design in the U.S. has been mostly evolutionary in nature. Current standard navigational buoy designs are generally based on what has functioned adequately in the past. These designs have been modified to improve visibility, durability, maintainability, producibility, handling safety and/or to accommodate payload changes. The design modifications were also implemented to suit changes in the requirements and in the systems' ability to deal with them.

Throughout the years, the USCG has kept constant vigil on the SRA system and has sought to improve its function. The present SRA system has evolved from the time of riveted buoy hulls and from where the size of the buoy was dictated by the stability requirements to support the weight of the payload including heavy acetylene accumulators. The first electric buoy was tested and adopted for service in 1930. The batteries used then were mounted on large, heavy battery racks.

The size and the general construction particulars of USCG buoys have not changed appreciably even up to the present day. In 1962, however, a major

milestone in USCG buoy development was accomplished and a series of standard buoy designs incorporating modifications to battery pockets to accommodate smaller and lighter battery racks for improved batteries as well as other modifications dictated by the changes in ATON requirements was developed.

Some of the major USCG buoy research and development efforts accomplished since 1962 include the following:

- In 1967, the USCG began using a modified version of the "Monster Buoy" to replace lightships and towers. (This large navigation buoy (LNB) is excluded from the present study but is an example of the innovation that is desired.)[1]

- In 1968, the USCG launched a program to study the use of plastic materials for navigational buoys.[2]

- In the early 1970's, the USCG undertook to measure and analyze the motions of several lighted buoys to investigate the effects on payload.

- In the early 1970's, the USCG identified selected improvements in buoy hardware to increase the standard relief (overhaul) cycle for coastal buoys to six years from three years.

- The USCG designed and tested plastic fast-water buoys in 1976.[3]

- The USCG, in 1984, developed guidelines for evaluation and design of Aids to Navigation in restricted waters.[4]

Presently, the USCG maintains approximately 4,155 lighted and 21,830 unlighted buoys in the SRA system for a total of 25,985 buoys. This is more than twice the number in Canada which has the second largest SRA system in the world. It is many times more than the number for the countries with the next largest buoyage systems. These include Denmark, England, Finland, France, Germany (Fed. Rep of), Japan, the Netherlands and Norway.

To meet the changing ATON requirements, there is still scope for the improvement of buoys, both through evolution and innovation. The USCG has identified a number of areas within the buoyage system where the potential for improvement exists. These are discussed in the following sections of this report.

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[1]Meyers, et. al., Handnook of Ocean and Underwater Engineering, 1969.

[2]P.J. Glahe, A History of the Development of Plastic Buoys by the United States Coadst Guard, IALA Conference, No. 3.1.5, Tokyo, 1980.

[3]P.H. Glage, Design, Procurement and Testing of Plastic Fast Water Buoys on the Arkansas River, USCG, 1976.

[4]Smith, M.W., et. al., Aids to Navigation's Principal Findings Report: Validation for a Simulator-Based Design Project, CG-D-06-84, 1984.

1.3 The Buoy Platform

A brief review of the general characteristics and function of the buoy platform, or hull, is in order since it is the main concern of this project.

The buoy hull, as a primary component of the ATON complex, must provide the necessary buoyancy and positive stability for all conditions. It must support its own payload including power supplies, electronic equipment and antennae. It must also sustain the mooring forces and those of the environment including wind, current and wave drag. The positive stability will assure the buoy will not capsize due to the environmental loads or during routine maintenance operations. This may be accomplished by the proper location of weights, counterweights and by the design of the buoy geometry itself. The buoy hull must also have adequate structural integrity to resist damage during launching/retrieval operations and while on station.

Figures 1-A and 1-B show the buoy components and the terms used in identifying them for a typical lighted buoy and for an articulated beacon, respectively. The complete buoy nomenclature used by the USCG for identifying all types and sizes of aid to navigation buoys is shown in Table 1.

The USCG has detailed data sheets for its buoys in COMDINST.M16500.3, "Aids to Navigation Manual - Technical". A sample data sheet from the above-mentioned manual for the 9x32 LR buoy is reproduced in Figure 2. As seen, the data sheets provide the function, physical and operational characteristics, equipment, and other additional data applicable to the specific buoy. Buoys are classified as suitable for exposed, semi-exposed, or protected environmental conditions in both ocean and fast water (i.e. high current) environments.

In selecting a buoy the following must be considered:

- o Application
- o Environment
- o Signal Requirements
- o Positional Accuracy Requirements

The standard floating aid to navigation buoys currently being used by the USCG in coastal and inland waterways, in the Great Lakes, and the western rivers regions are shown in the following illustrations:

The ATON manual contains complete illustrations and data sheets for all of these standard buoys as well as their variations such as bell/gong/whistle buoys, etc.

TABLE 1
Abbreviations Used in the Classification
and Designation of USCG ATON Buoys

For Unlighted Buoys:

(Except Unlighted Sound)

C	CAN (Cylindrical Buoy Shape)
N	NUN (Conical Buoy Shape)
T	Tall Buoy
S	Special Buoy
P	Plastic Buoy
A	Aluminum Buoy
R	Buoy with Radar Reflector
F	Fast Water Buoy
M	Mooring Buoy
D	Drum or Barrel Buoy
SPAR	Spar Type Buoy

For Lighted Buoys and Unlighted Sound Buoys:

L	Lighted Buoy
B	Bell Buoy
G	Gong Buoy
W	Whistle Buoy
E	Electrical Bell Striker
H	Horn
I	Ice Buoy

Standard Buoy Designations

9 x 35 LR
9 x 32 LR, LGR, LBR, LWR
9 x 20 BR, GR
8 x 26 LR, LBR, LGR, LWR, WR
7 x 17 LR, 7 x 20 LI
6 x 20 LR, LBR
3 1/2 x 8 LR, 5 x 11 LR
1 CR, NR
2 CR, NR
3 CR, NR, CI, NI
4 CR, NR
5 CR, NR, CPR, NPR, CI, NI
6 CR, NR, CT, NT, CPR, NPR
FCPR

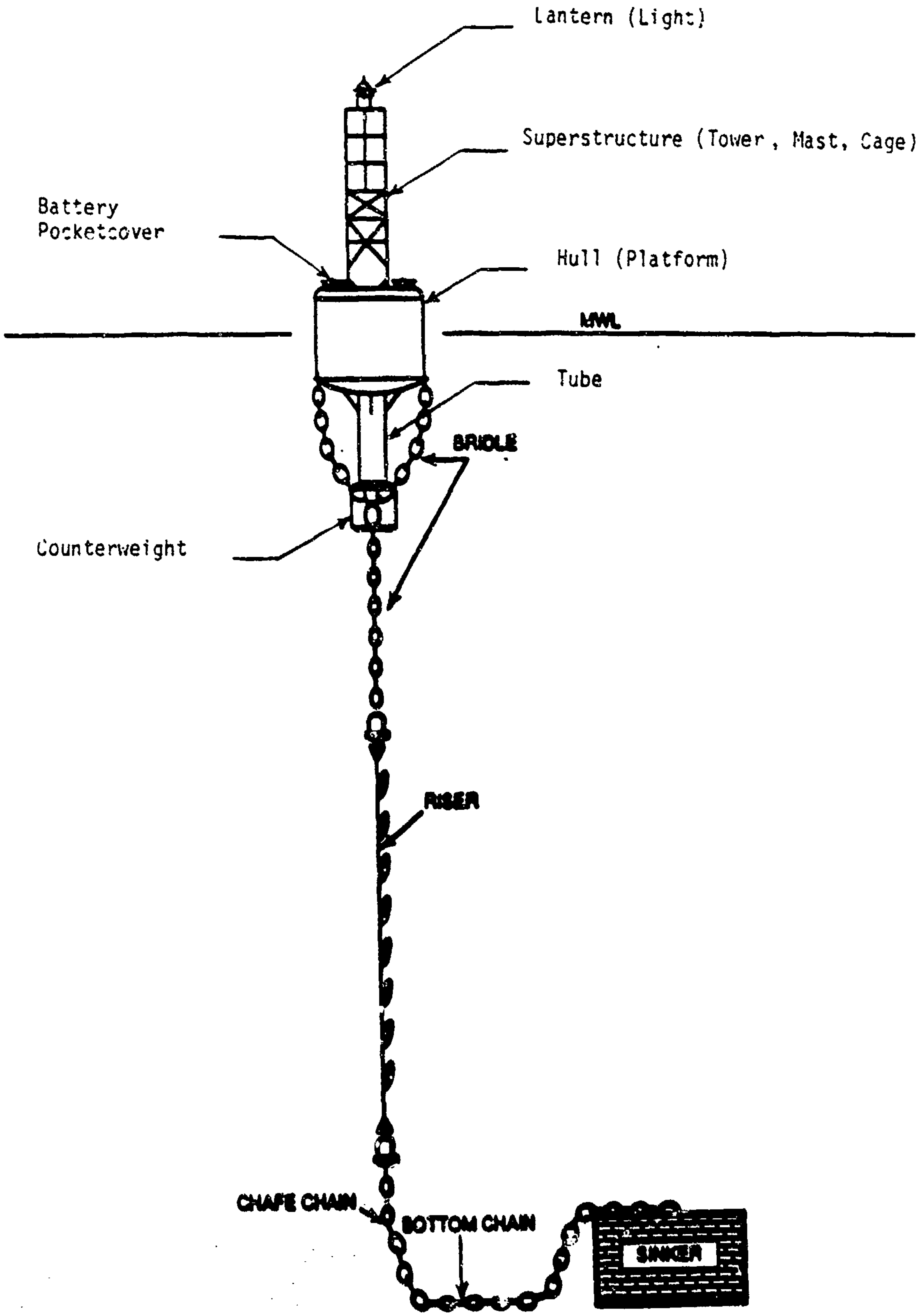


Figure 1-A

Components of a Floating Aid to Navigation Buoy Systems

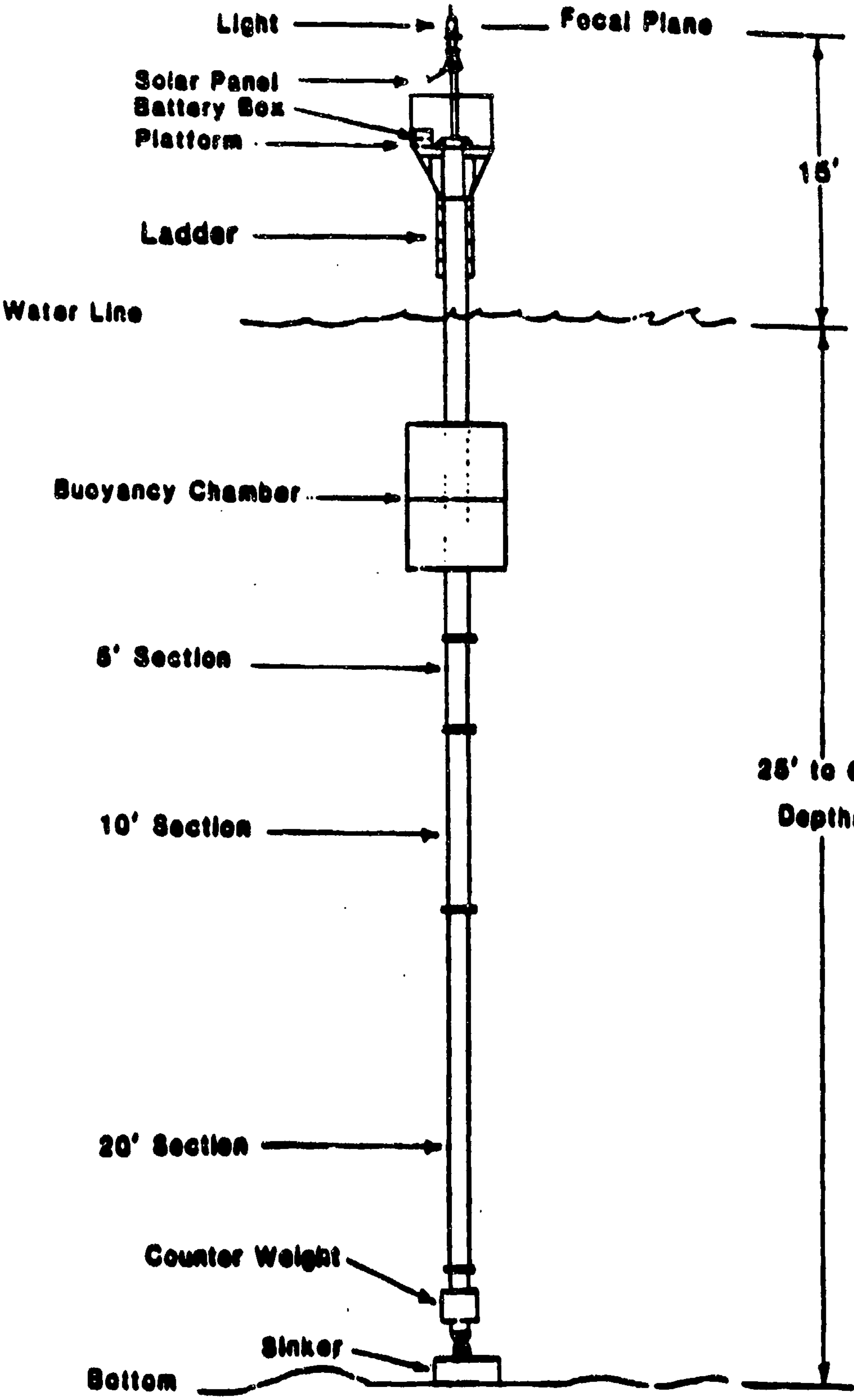
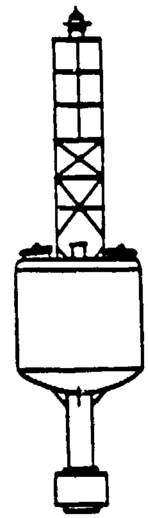


Figure 1-B
Components of an Articulated Buoy



1962 TYPE
STANDARD

Function. The 9X32 LR buoy is designed and constructed for the most exposed locations. This buoy configuration is used when a sound signal is not required.

Physical Characteristics

Buoy weight	17,443 lb
Buoy draft (no mooring)	11 ft-9 in.
Focal height of light (no mooring)	20 ft-2 in.
Freeboard (no mooring)	4 ft-5 in.
Minimum freeboard	1 ft-4 in.
Pounds per inch of immersion	340

Related Equipment

Power units (maximum number and size)	2-830
Bridle size (chain diameter and length)	1¼ in.X18 ft
Mooring chain size	1¼ in.
Sinker size	12,750 lb

Operational Characteristics

Nominal visual range of daymark	3.8 nmi
Radar range	4.5 nmi
Maximum current	5 kn
Visual range of light	(see Chapter 6)

Operational Characteristics (cont'd)

Minimum mooring depth	30 ft
Maximum mooring depth (810)	345 ft
(830)	325 ft

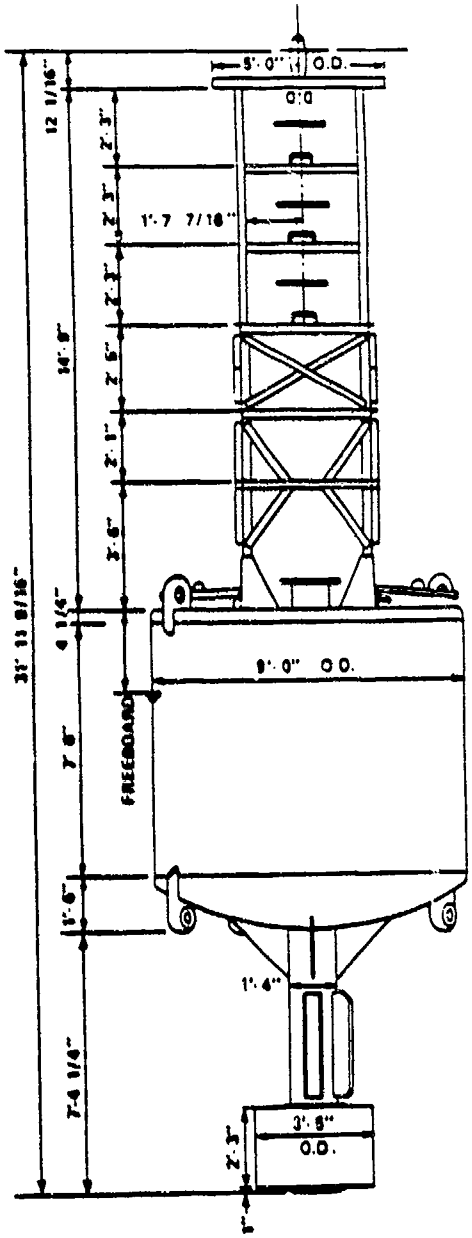


Figure 2

Sample Data Sheet for 9 x 32 LR Buoy
(From ATON Manual-Technical)

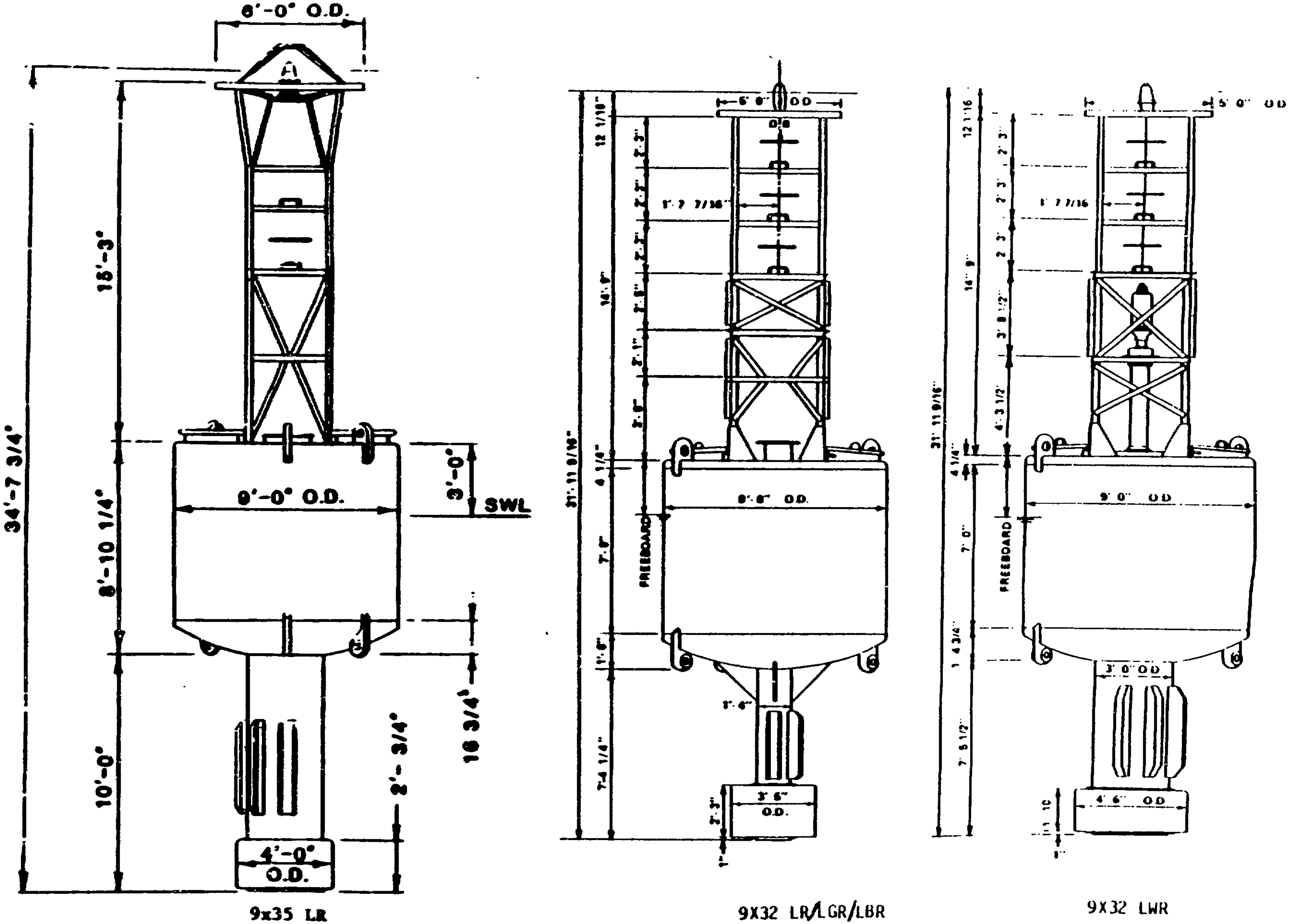


Figure 3: Standard 9 Ft. USCG Buoys

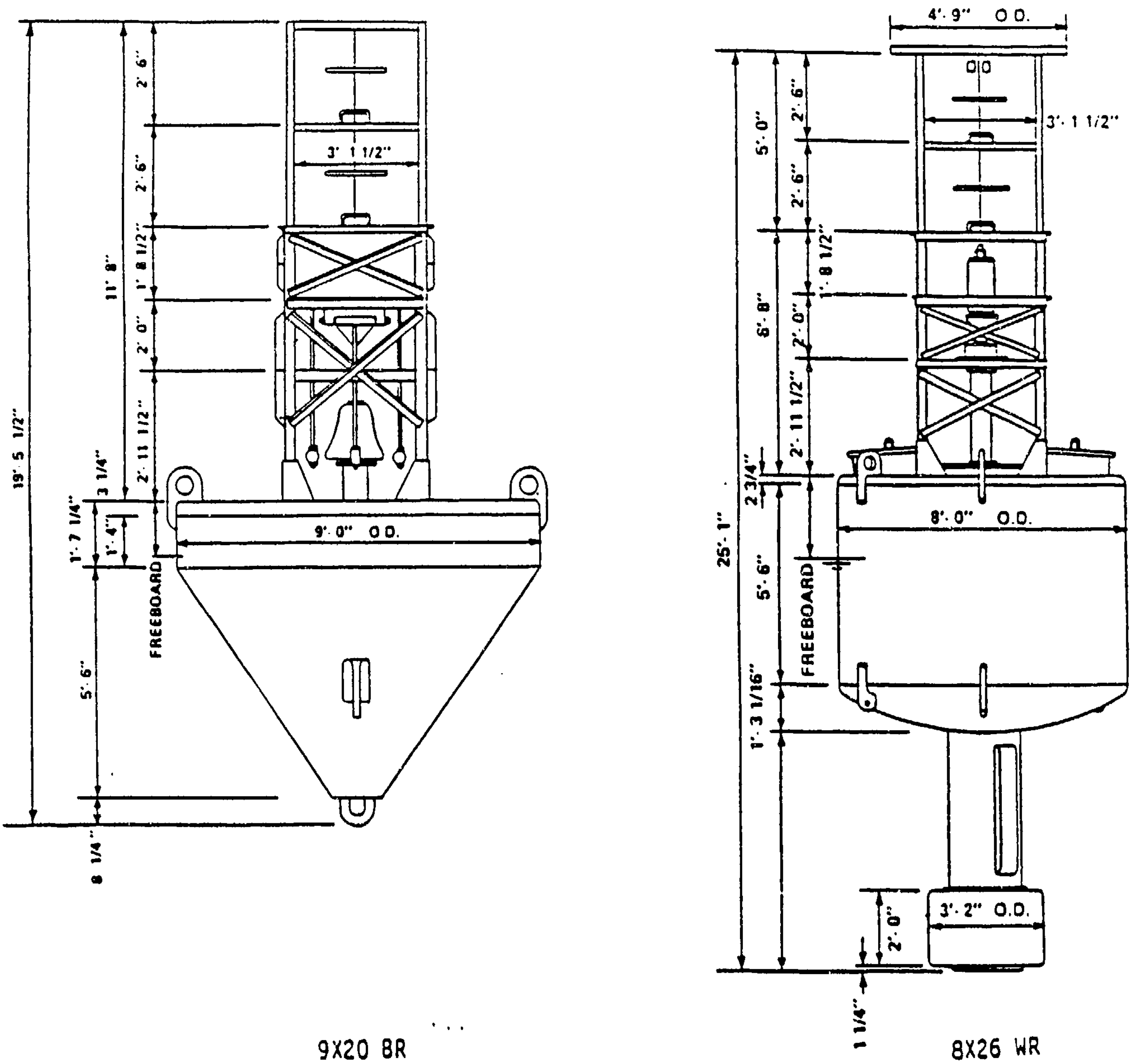


Figure 4

Standard 9 x 20 and 8 x 26 USCG Buoys

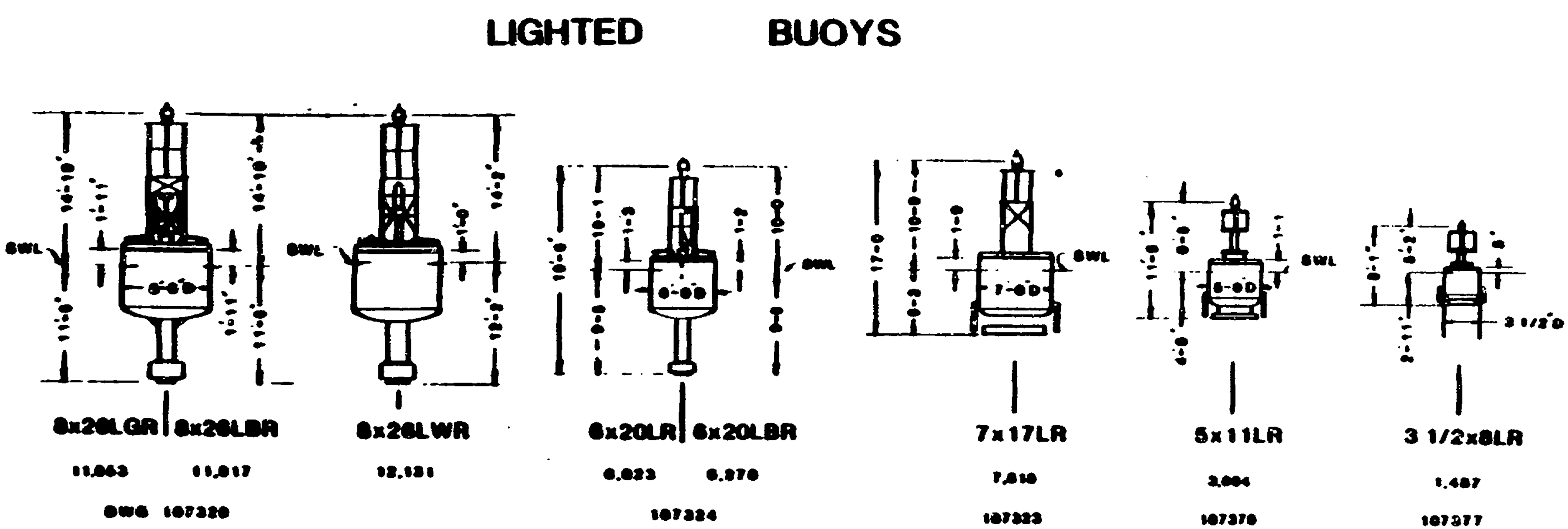


Figure 5

Standard Lighted USCG Buoys

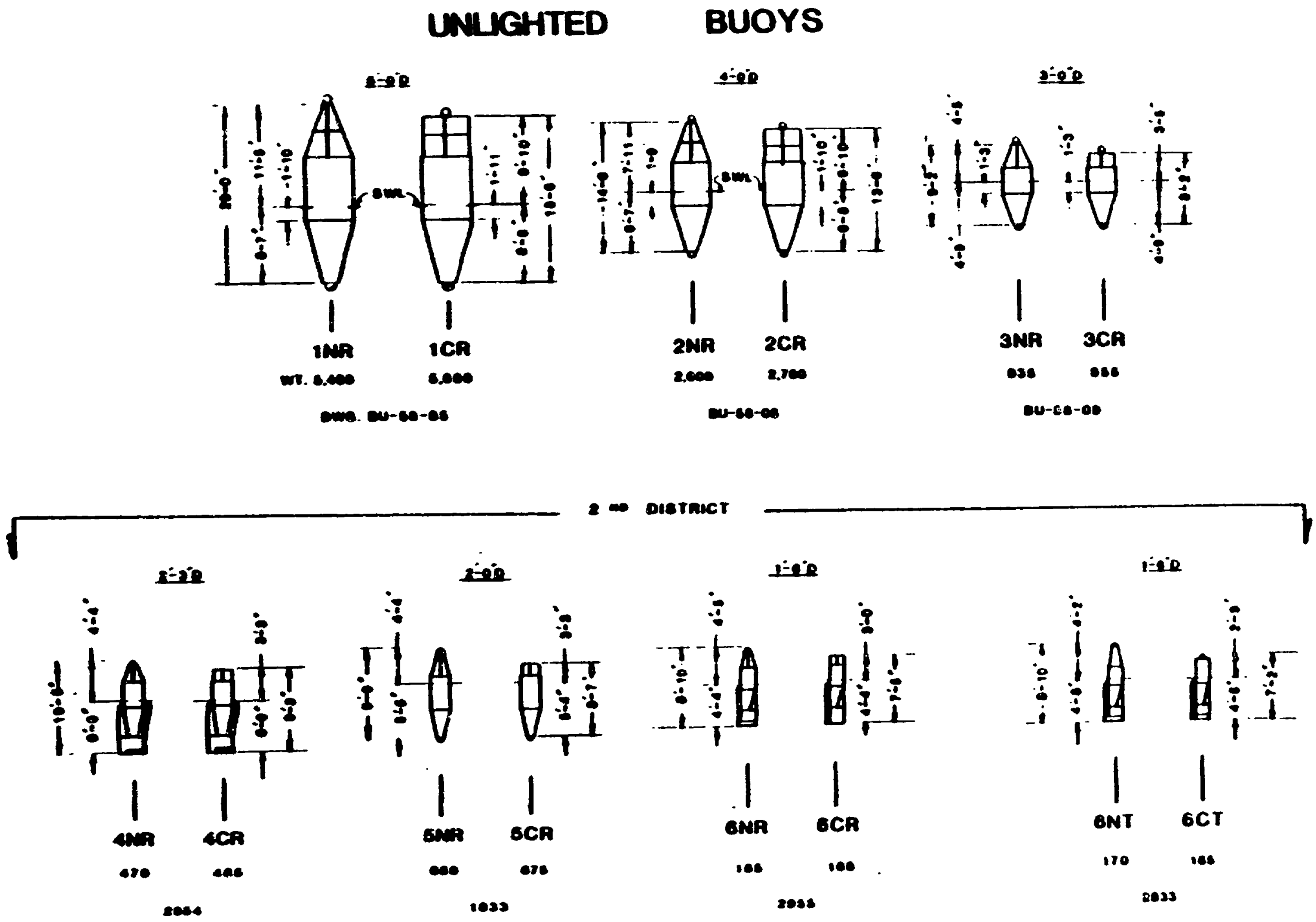


Figure 6: Standard Unlighted USCG Buoys

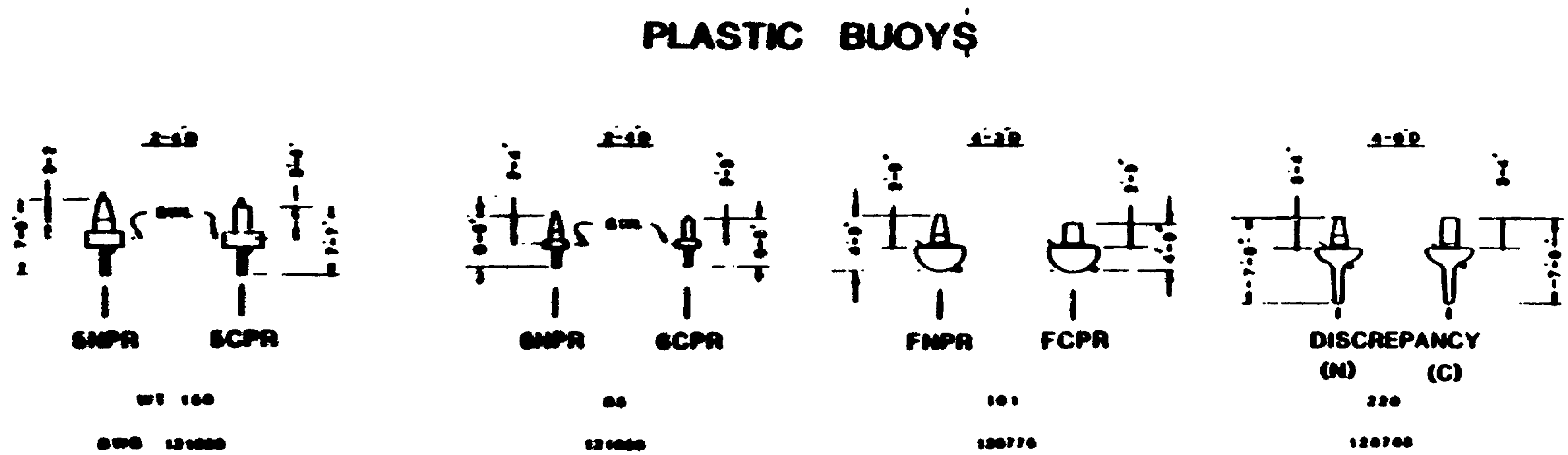


Figure 7: Standard Plastic Buoys

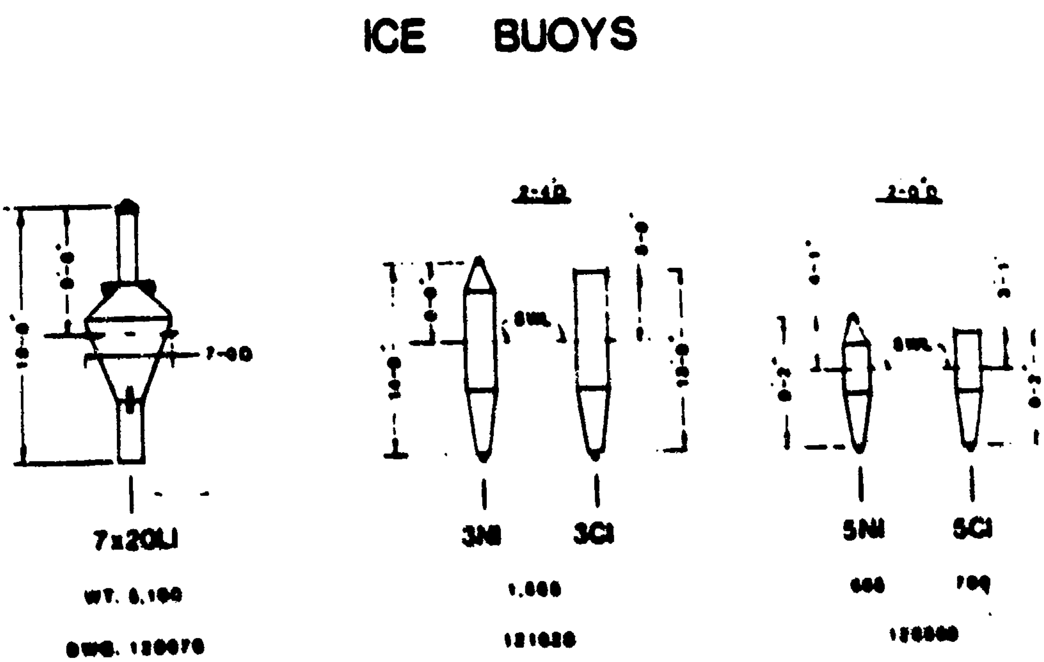


Figure 8

Standard Ice Buoys

1.4 Task A: USCG Buoy Development Review

1.4.1 Objectives

This task consists of the preparation of a review and summary of the research and development efforts by the USCG on aid to navigation buoy development since 1962.

The objectives of this effort are as follows:

- o Organize, summarize and preserve the information gained from USCG buoy development work.
- o Identify problem areas where R&D efforts have not produced a solution.
- o Identify areas to be reassessed based on recent advances in related technology.
- o Identify areas to be reassessed based on recent developments related to changes in USCG operational practices.
- o Identify areas to be reassessed based on requirements associated with IALA conformance.
- o Provide background for the recommendations for development to be prepared under Task C.

1.4.2 Approach

Sub-task A-1: Literature/Document Review

MR&S has reviewed all available technical documents and literature relating to USCG aid to navigation buoy design or development since 1962 as obtained from the following sources:

- o USCG Research and Development Center Library in Groton, CT
- o USCG Headquarters (Office of Navigation and Waterway Safety and Office of Engineering, Logistics, and Development), Washington, D.C.
- o Department of Transportation (DOT) Library, Washington, D.C.
- o Defense Technical Information Center (DTIC)
- o National Technical Information Service (NTIS)
- o IALA Conference Proceedings and Quarterly Bulletins
- o The Coast Guard Engineer's Digest
- o USCG Aids to Navigation Bulletins
- o Miscellaneous marine publications and information sources

A total of 203 documents have been identified and reviewed. Details of the Literature/Document Review are presented in Section 2.0 of this report.

Sub-task A-2 Interviews: USCG Authorities and Buoy Manufacturers

MR&S has interviewed USCG management personnel involved with buoy designs, maintenance or development at the following locations:

- o USCG Headquarters, Washington, D.C. (G-ECV, G-NSR)
- o USCG R&D Center, Groton, CT (New Buoy Systems Project Office)
- o USCG District Aids to Navigation Division Chief for Districts 1 (Boston, MA), 2 (St. Louis, MO), 8 (New Orleans, LA), 9 (Cleveland, OH) and 13 (Seattle, WA)
- o USCG Base St. Louis, MO
- o USCG Detachment, National Buoy Data Center, Bay St. Louis, MS
- o USCG Governor's Island, NY, Buoy Depot
- o USCG Weymouth, MA, Buoy Depot
- o USCG Mobile, AL, Buoy Depot
- o USCG National ATON School, Yorktown, VA

Additionally, the following individuals and/or manufacturers were interviewed during Task A:

- o Automatic Power Inc., Houston, TX
- o Bahr Technologies, Inc., Madison, WI
- o Tideland Signal Corp., Houston, TX
- o Gilman Corp., Inc. Gilman, CT
- o Benthos, Inc., Falmouth, MA
- o Woods Hole Oceanographic Institution, Woods Hole, MA
- o VADM. R. Price, USCG (Ret.) (Maritime Consultant-Naval Architect)

All interviewees were contacted in advance of the visit and provided with an advance copy of the interview format and agenda. The results of the interviews with USCG personnel are presented in Section 3.0 of this report. Results from interviews with manufacturers and private individuals will be presented in the Task B report.

Sub-Task A-3: Summary of Reviews and Interviews

In this sub-task, comprehensive summaries were prepared of the various aids to navigation research and development efforts identified in the

literature review and personnel interviews.

The summaries of literature search include the following:

- o Synopsis of the objectives of the work
- o Approach
- o Results
- o Conclusions
- o Recommendations
- o Performing organization
- o Key personnel
- o Reference documentation and/or information sources

The summaries of personnel interviews include the following:

- o Organization
- o Person interviewed
- o Personnel's experience with buoys
- o Types of buoys and environment
- o Synopsis of interviewee's impression of USCG Buoy development
- o Problems with current SRA systems
- o Ideas for improvements
- o Impact of IALA conformance

The results of literature reviews and USCG interviews are discussed in detail in Section 2.0 and 3.0 of this report. Supporting information for interview results is provided in Appendix A which contains a synopsis of the comments (as recorded) during interviews with USCG authorities.

Sub-Task A-4: Bibliography

A bibliography has been developed from the literature reviewed and from the references and information sources cited therein. It has been subdivided into technical subject areas relating to principal topics in accordance with the following list:

- o General
- o Materials
- o Performance

- Interfaces

- Innovative Concepts

The bibliography is given in Appendix B, and as stated, contains 203 entries. Abstracts for selected references from the bibliography is presented in Appendix C.

2.0 RESULTS OF LITERATURE/DOCUMENT REVIEW

2.1 General

All available technical documents and literature relating to buoy platform design and development published since 1962. The publications encountered in this review have been organized in a comprehensive bibliography presented in Appendix B. A bibliographic computer database was also developed as discussed below in Section 2.4.

The primary criterion for inclusion in this bibliography was the publication's relevance, either directly or indirectly, to the field of floating aid to navigation design. Documents dealing with related buoy types, such as data buoys, were included if the information presented was judged to be applicable to aid to navigation systems. The primary focus of the search was the design and performance of the buoy platform itself, however selected documents dealing with moorings, payload, and other ancillary subjects were included if they introduced new or unique technology or provided information that might be useful to the aid to navigation designer.

Abstracts from Bibliography entries which are most closely related to the subject matter of this project have been prepared and are presented in Appendix C of this report. The preparation of abstracts is discussed in greater detail in Section 2.3 below.

Several of the documents reviewed during the literature search were found to be directly related to U.S. Coast Guard research and development projects. In order to preserve this information, these projects have been summarized based on data obtained from project reports, conference papers, or USCG files. These descriptive summaries are further discussed in Section 2.5 below.

2.2 Sources

MR&S has consulted a number of sources, both government and private, in the execution of this literature search. The government sources consulted are listed under Subtask A-1 in Section 1.4.2. The following additional informational sources were consulted and appropriate reference materials were reviewed and included in the Bibliography:

- o National Data Buoy Center Technical Repository and Engineering Library, Bay St. Louis, MO
- o Oceans Conference Proceedings published by the Marine Technology Society (MTS) and the Institute of Electrical and Electronic Engineers (IEEE)
- o Buoy Technology Conference Proceedings published by the Marine Technical Society (MTS)
- o Society of Naval Architects and Marine Engineers (SNAME) Annual Transactions
- o Offshore Technology Conference Proceedings

In addition to the above mentioned sources, several documents, both published and unpublished, were made available via personal files of individuals contacted during the personnel interviews.

2.3 Abstracts

The selection criteria for bibliographical compilation are listed in Section 2.1 above. The compilation consists of 203 entries, each listing the title, author, source of publisher, and year of publication. The entries are organized according to the subject matter categories in Section 2.1. The scope of information included in each subject matter category is as follows:

- o General - Publications which give general design information or provide miscellaneous data which may be useful to an aids to navigation designer.
- o Innovative Concepts - Publications which present unique or novel buoy designs or solutions to buoyage problems.
- o Interface - Publications dealing primarily with buoy interfaces with the environment, the sea floor, or the mariner, i.e., mooring systems, lighting systems, power supplies, and buoy detection characteristics.
- o Materials - Publications dealing with construction or coating materials for aids to navigation.
- o Performance - Publications dealing with buoy performance prediction and evaluation including computer models, mathematical theories, and wave tank tests.

The abstracts presented in Appendix C were taken directly from the article's own abstract whenever possible. In the case where no abstract was readily available, summaries were prepared based on a close review of the publication. A total of 149 entries from the bibliography were abstracted and arranged in categories consistent with those of the bibliography.

2.4 Bibliographic Computer Database

The bibliography compiled during the literature review was entered into a computer database on the Coast Guard supplied UNISYS computer using the PROGRESS database software package. The following is a description of the database structure:

The database consists of a single file containing all of the bibliographic records. Each record contains six (6) fields: publication number, category, bibliographic entry, publication date, country, and abstract.

The publication number is simply a unique marker for each record. Its intended use is to track the order in which the records were originally entered into the database and to provide a method of accessing the records for editing purposes.

The category is the subject heading under which the entry should appear in the bibliography.

The bibliographic entry field contains the author, title, and publication information for each entry. The publication date field is filled only if a specific date of publication is available.

The country field designates the national affiliation of the authors of the title.

Finally, the abstract contains a summary of the publication either compiled after review of the document or taken directly from the article itself. The specific names and formats of these fields are presented in Table 2.

2.5 Summaries of USCG R&D Efforts on ATON

The descriptive summaries that appear in the following pages are the result of the literature search performed under Task A-1 of this project. These summaries document research efforts with regard to Aid to Navigation Buoys by or for the U.S. Coast Guard from 1962 to the present. The projects presented in this section were selected with an emphasis on those efforts devoted primarily to the development and performance of buoy platforms. Projects devoted to payload, mooring, and other equipment were only included if they constituted a unique effort or introduced technology superior to that already in existence.

The summaries are organized according to subject matter in following sequence:

1) Articulated structures (Nos. 1 and 2)
2) Plastic and foam buoys (Nos. 3 through 12)
3) Buoy performance prediction and evaluation (Nos. 13 to 16)
4) Buoys for severe environments (Nos. 17 to 20)
5) Unique equipment studies (Nos. 21 and 22)
6) Miscellaneous projects (Nos. 23 to 27)

TABLE 2

Bibliographic Database Field Formats

Database Name: biblio
File Name: pub2

FIELD	FIELD NAME	FORMAT
Publication No.	pub-numb	4-digit integer
Category	categoryb	30 character
Bibliographic Entry	Bib-ent	Array of 8 rows x 60 characters
Publication Date	pub-dateb	Date format 99/99/99
Country	countryb	35 characters
Abstract	abstractb	Array of 17 rows x 60 characters

Each summary adheres to the following format:

1) Project Title

2) Dates - Time period during which work was accomplished.

3) Objective - Overall goal or intent of the project and any initial requirements which the end product of the study was expected to satisfy.

4) Approach - Description of the sequence and type of work performed during the study.

5) Results and Conclusions - Description of the end product of the study and an evaluation of its fulfillment of the project objective.

6) Recommendations - Recommendations for future work or application of the results of this study.

7) Performing Organization(s) - Private or USCG organization(s) involved in the project.

8) Key Personnel - Those individuals who contributed significantly to or have detailed knowledge of the project as determined in the literature search.

9) References/Sources - Any sources identified in the literature search as providing significant information about the project. These may include published reports, unpublished reports, and USCG files.

PROJECT SUMMARY NO. 1

ARTICULATED BEACON DEVELOPMENT

DATES: 1980 to Present

OBJECTIVE:

The purpose of this effort is to design an articulated beacon (AB) for use as a short range aid to navigation. An AB consists of a steel pipe structure that pivots around a universal joint connecting it to a sinker. The beacon is kept in a vertical position by means of a subsurface floatation collar, resulting in zero watch circle. While an AB has approximately the initial cost as an 8 x 26 lighted buoy, it has the same potential for significantly lower maintenance costs. It can be serviced by two people in a small servicing craft. Its projected on-station life expectancy is 10 years, with periodic mooring inspections of the universal joint by a diver. In addition, it is compliant in a collision situation.

APPROACH:

The development of this beacon began with a study commissioned from the University of Rhode Island to develop a generalized analytical model to be used in the design of an articulated structure. Prototype articulated structures were tested in a laboratory flow channel and in the field to validate this model.

The Coast Guard then undertook the design and construction of two full-scale prototype lighted aids to navigation and tested them in the Newport News channel to validate the concept. A second generation design was then developed to incorporate a self-imposed constraint that it be deployable and retrievable by Coast Guard buoy tenders (vs. contracting out the deployment/retrieval). This constraint forced engineers to sectionalize the design and keep the overall weight as low as possible due to the buoy tender's boom reach, weight handling limitations, and working deck area.

The latest effort has been to design another generation of ABs which are extremely effective in protected harbors, semi-exposed areas and open seas. They will work equally well in shallow water (less than 20 meters when connected directly to the sinker), deep water (up to 200 meters using a taut mooring), fast current situations (up to 8 knots) and high tidal areas.

RESULTS AND CONCLUSIONS:

The current AB design consists of a vertical pipe attached to a sinker via a universal coupling. Buoyancy is provided by a foam flotation collar mounted on the pipe below the waterline. The beacon is designed for water depths of 20 to 60 feet, tide ranges of 5 feet, and currents of up to 2 knots.

Operational evaluation of the beacons have revealed several problems. Both the universal coupling at the sinker and the connecting flanges for the pipe sections were prone to premature failure. These weak components have been redesigned. Field experience also indicates that the AB is compliant. One beacon survived 7 collisions. The quality of the original foam floats was found to be poor, resulting in shrinkage and water intrusion, causing a loss

of initial buoyancy and increased wear on the universal hinge. Better quality control during manufacturing of foam appears to have alleviated the problem. The expected service life of 10 years was not realized. Service life estimates from field units range from 2 to 5 years. Part of this reduction in life span appears to be due to an inferior coating system resulting in excessive corrosion.

Aside from the survivability problem, the structure appears to perform well as a navigational aid in currents up to 2 knots. At that point, the structure assumes an angle which tilts the focal plane of the signal light out of the horizontal. A prototype has now been deployed in which the optic has been fitted into a gimbal to keep the light in the focal plane.

It would appear that the second generation articulated beacon design did not show all of the advantages expected at the outset of the project. Most of the problems, however, appear correctable with design modifications to subsequent generations.

RECOMMENDATIONS:

The predominant recommendations which appeared during this design effort were:

1) Maintain better quality control over the foam floats
2) Investigate the use of lighter construction materials
3) Improve the coating system
4) Redesign the foam float, sinker bail, and counterweight configuration

PERFORMING ORGANIZATION(S):

USCG R&D Center
USCG Headquarters
University of Rhode Island Ocean Engineering Dept.

KEY PERSONNEL:

S. Walker (USCG)
P. Glahe (USCG)
D. Strahl (USCG)
J.W. Cutler (Univ. of R.I.)

REFERENCES/SOURCES:

References related to this project may be found under the following entry numbers in Appendix B: 32, 68, 74, 78, 85, 98, 99, 103, 104, 105.

PROJECT SUMMARY NO. 2

COLLISION TOLERANT PILE STRUCTURE PROJECT

DATES: 1985 to 1987

OBJECTIVE:

The purpose of this project was to develop a collision tolerant pile structure (CTPS) for use as a short range navaid in shallow water areas.

APPROACH:

The initial development of the CTPS was accomplished at the University of New Hampshire using a two-dimensional computer model and a 1/15 scale physical model incorporating a peripheral stay hinge. The physical model was tested in current and for scaled barge collisions. Later, under a Sea Grant student project, a 1/4 scale model was built and tested. Two hinge concepts were investigated: a peripheral stay hinge and a central stay hinge. The experiments tested spring pre-tension, hinge moment-angle behavior, collision recovery, and wave response performance.

RESULTS AND CONCLUSIONS:

The CTPS developed in this project was a single pile, hinged at the mudline and was designed to operate in 30 ft. of water. The peripheral stay hinge design consists of four wire stays which angle up from the lower half of a universal coupling to the inside of the upper pile structure. The stays then connect to a pre-tensioned spring at the center of the pile. The central stay hinge consists of one wire rope which extends from a base at the bottom of the structure through the center of the hinge and connects to a multistrand, pre-tensioned spring running through the center of the upper pile.

The tests showed that both hinges provided 100% recovery from barge collision with no damage. Also, both designs were observed to remain motionless and vertical in two foot waves (8 ft. full scale) and showed minimal movement during wave impact tests.

In summary, after limited testing, both CTPS designs appeared to meet all requirements for motion and impact resistance. A comprehensive evaluation, however, would require full scale testing of the concept.

RECOMMENDATIONS:

Because the central stay hinge requires a smaller spring pretension, has fewer moving parts, and is more compact, it is recommended that full scale prototype development be pursued using the central stay hinge concept.

PERFORMING ORGANIZATION(S):

University of New Hampshire, Mechanical Engineering Department and Ocean Engineering Program.

U.S. Coast Guard Research & Development Center (sponsor).

KEY PERSONNEL:

Dr. K. C. Baldwin (U.N.H.)
Dr. M.R. Swift (U.N.H.)
D.J. Mielke (U.N.H.)
Robert Cloutier (U.N.H.)

REFERENCES/SOURCES:

References related to this project may be found under the following entry numbers in Appendix B: 75, 80, 101.

PROJECT SUMMARY NO. 3

FOAM BUOY DEVELOPMENT PROJECT

DATES: 1982 to 1988

OBJECTIVE:

The purpose of this project was to investigate the use of new flexible ionomer foam materials and construction techniques for use in the construction of a new family of lightweight unlighted buoys. Such buoys are expected to last longer, cost less, and resist collision damage better than the current steel and plastic designs.

APPROACH:

As a first step, a small buoy (6th class) was designed using Surlyn ionomer foam. The construction method consists of concentrically wrapping sheets of the foam and heat-sealing each layer upon itself. The outer surface is then densified to make the buoy watertight. Seventy of these small buoys were constructed and tested along the Texas Gulf coast.

A larger buoy (the size of a 2CPR) was then designed using the same material. Twenty-two of these were built and tested on the Mississippi River where there is a high probability of collision.

Finally, a complete family of buoys was designed and procured for operational use.

RESULTS AND CONCLUSIONS:

The end product of this project was a family of lightweight unlighted ionomer foam buoys covering the 2nd class to 6th class buoy sizes. The foam coloring is impregnated into the material along with an ultraviolet blocking agent to enhance colorfastness. Radar reflectivity was originally accomplished by a wire mesh embedded in the buoy topmark, but now a biplane metal reflector fit into slots on the upper foam section is used.

Field evaluation has shown that these buoys perform very well. The buoys stay brighter than both the steel and plastic buoys, they do not sink, they return to their original shape after deformation, they require minimal maintenance, and they allow the use of smaller mooring gear. They are not easily damaged in collisions, and when they are damaged, the inherent buoyancy of the foam and through-body coloring allow them to remain functioning aids. Further, they can be deployed and serviced by small boats.

Initially, the buoys cost more than either the steel or plastic buoys, but with improvements in construction methods and purchase in large quantities the initial cost has been reduced significantly.

RECOMMENDATIONS:

It has been recommended that the buoys designed in this project be used in areas where loss rates are high due to barge traffic and where above average maintenance of steel buoys would be required.

PERFORMING ORGANIZATION(S):

USCG R&D Center

KEY PERSONNEL:

P.J. Glahe (USCG)
K. Heinz (USCG)

REFERENCES/SOURCES:

References related to this project may be found under the following entry numbers in Appendix B: 27, 68, 145, 146, 151.

PROJECT SUMMARY NO. 4

2 CPLR LIGHTED FOAM BUOY PROJECT

DATES: 1986 to 1987

OBJECTIVES:

The purpose of this project was to test the feasibility of a modified 2CPR foam buoy fitted with a solar powered lighting package. Such a buoy could be used in place of the 3-1/2 x 8 LR and 5 x 11 LR buoys, both of which use conventional battery power.

APPROACH:

A standard 2 CPR buoy was equipped with a lantern and solar panel on top of the daymark and a waterproof plastic battery box was fitted into a cavity cut into the foam buoy body. The counterweight was extended 18 inches with a lead-filled pipe in order to maintain the stability of the buoy with the additional topside weight. In addition, a 5 x 11 LR buoy was also fitted with a solar panel and counterweighted.

Both buoys were deployed, along with a lighted discrepancy buoy, in Fishers Island Sound and subjected to field tests. These tests compared the buoys on the basis of righting ability, ease of deployment, light and daymark visibility, radar range, and hull performance.

After this first series of tests, design changes were made to the 2CPR buoy and the tests were performed again. At this time a foam radar reflective daymark was also tested and used on the buoy.

RESULTS AND CONCLUSIONS:

The 2CPR Foam buoy was successfully modified to accept a solar panel, light and battery as described above. Testing showed that the solarized foam buoy performed as well as the 5 x 11 LR buoy in seas up to 5 ft. and winds up to 37 mph. It also performed better than the lighted discrepancy buoy in the same conditions. With a hollow daymark, the foam buoy exhibits satisfactory stability and motion characteristics. The lightweight foam radar reflectors were found to perform as well as the 5 x 11 LR's aluminum reflector, although they are not as easily stacked for storage. The 2 CPR buoys also proved much lighter and easier to handle than the 5 x 11 steel buoy.

In summary, the feasibility of a solar powered foam buoy has been proven. Also, it was shown that current steel buoys like the 5 x 11 LR and 3-1/2 x 8 LR can be successfully solarized.

RECOMMENDATIONS:

The primary recommendation offered at the conclusion of this project is that the 2 CPR foam buoy should continue to be developed as a lighted aid to navigation.

PERFORMING ORGANIZATION(S):

USCG R&D Center

KEY PERSONNEL:

J.A. Arnquist (USCG)

REFERENCES/SOURCES:

References related to this project may be found under the following entry numbers in Appendix B: 68, 71, 73, 74.

PROJECT SUMMARY NO. 5

4 x 11 LIGHTED FOAM BUOY PROJECT

DATES: 1985 to 1987

OBJECTIVE:

The purpose of this project was to design a lighted foam buoy which can be used to replace the 5 x 11 LR and 3-1/2 x 8 LR steel buoys. The buoy should be unsinkable, flat-bottomed, and capable of being deployed by 46 ft. boats.

APPROACH:

The design of the buoy centered on developing a rugged buoy similar to the existing small lighted steel buoy. It was decided to use foam as the floatation element and steel and aluminum as the support structure. The buoy was also designed to accommodate a solar panel and battery case.

Five of the prototype buoys were constructed and tested in the field for 6 months. They were evaluated on the basis of servicing, deployment, and operation.

RESULTS AND CONCLUSIONS:

The buoy which resulted from this project is 4 feet in diameter with a foam body, steel structure, and triangular aluminum radar reflector. These buoys performed very well in field testing. They were easy to service, very stable and easy to store due to the flat bottom. The field units judged that they performed better than the existing 3-1/2 x 8 LR and as well as the 5 x 11 LR.

The buoys did experience problems with water intrusion of the battery box and fastener corrosion. The deployment of the buoys in rough water areas indicated that performance may not be satisfactory for such conditions due to water constantly washing over the deck.

On the whole, the 4 x 11 LR buoy proved to be a successful design and is a viable replacement for the two sizes of buoy it was intended to replace.

RECOMMENDATIONS:

Based on the results of this project, it was recommended that development of the 4 x 11 LR buoy be continued. The design should be made a bit more rugged so that it may resist corrosion and water intrusion during rough water service.

PERFORMING ORGANIZATION(S):

USCG Office of Ocean Engineering (G-ECV-3B)

KEY PERSONNEL:

Geoff Abbott (USCG)
R.L. Boy (USCG)

REFERENCES/SOURCES:

References related to this project may be found under the following entry numbers in Appendix B: 1, 4, 68.

PROJECT SUMMARY NO. 6

FAST WATER BUOY DEVELOPMENT PROJECT

DATES: 1972 to 1978

OBJECTIVE:

The purpose of this project was to develop a buoy for service in fast currents such as found in the western rivers of the United States. The buoy should not submerge in fast currents, should resist debris accumulation, should be impact resistant, and should self-right in currents. Furthermore, the buoy should be low cost and have a 6 year service life.

APPROACH:

Initially, a Design Study Group was formed and initial possible configurations were developed. Those configurations deemed most likely to meet the buoy requirements were then field tested in different currents and water depths. The configurations were then narrowed down to a hemispherical buoy hull shape. A computer model was then developed and verified to predict the performance of various configurations. Hemispherical buoys were constructed and subsequently tested on the Arkansas and Piscataqua rivers. Based on these tests, operational prototypes were then designed and constructed. These designs were tested for self-righting, debris resistance and shedding, and collision resistance. Finally, operational versions of the buoys were produced and deployed on the Mississippi and Arkansas rivers where service evaluations were continued.

RESULTS AND CONCLUSIONS:

Of all the configurations considered and tested, the hemispherical buoy was judged best in meeting the requirements for service in fast water. Two sizes of the buoy (4 and 5 foot) were produced for evaluation. The smaller design was for currents of up to 6 mph and the larger for currents up to 8 mph. Both buoys are foam filled an have shells made of cross-linked, high density, polyethylene. The mooring eyes are placed at 35 degrees to the vertical to prevent diving in fast currents. Initial testing of the prototypes showed ballast needed to be added to improve the self-righting capabilities of both buoys. Operational evaluation showed that the buoys performed well as aids, especially in high current, and were superior to the old steel designs. The loss rate for these buoys was higher than for the steel buoys, mainly due to failure of the mooring and daymark mounting hardware. The debris shedding characteristics of the buoys are still not satisfactory and are believed to be one cause of the high rate of mooring failures.

RECOMMENDATIONS:

Due to design changes and better specifications, the price of steel buoys has dropped in recent years. Since the steel buoys are adequate in currents less than 4 knots, it was recommended that the plastic buoys be used in high current areas only.

Due to higher cost and lack of need for an 8 knot buoy, it was recommended that the larger plastic buoy be discontinued and only the smaller

buoy be produced. Since the conclusion of this project, the foot buoy design has been incorporated into the U.S. Coast Guard standard buoy mix as the FCPR and FNPR buoys.

Mooring and daymark mounting hardware should also be strengthened to reduce the loss rate of these buoys. Additional research should also be conducted on improving the debris-shedding capabilities of fast water buoys.

PERFORMING ORGANIZATION(S):

U.S. Coast Guard R&D Center

KEY PERSONNEL:

P.J. Glahe (USGC)
W.E. Colburn (USCG)
J.T. Tozzi (USCG)
D.D. Ryan (USCG)

REFERENCES:

References related to this project may be found under the following entry numbers in Appendix B: 81, 82, 88, 89, 153, 154, 188, 196.

PROJECT SUMMARY NO. 7

5TH AND 6TH CLASS PLASTIC BUOY PROJECT

DATES: 1972 to 1978

OBJECTIVE:

The purpose of this project was to develop a lightweight replacement for the Coast Guard's 5th and 6th class small steel buoys.

APPROACH:

The approach of the effort was centered on procuring and evaluating commercially available plastic buoys rather than developing a new design within the Coast Guard. Automatic Power, Inc. and Rolyan Manufacturing Co. were contracted to produce the buoys.

RESULTS AND CONCLUSIONS:

The buoys selected in this project are polyurethane foam filled and have a 1/8 inch thick shell of FRP, ABS plastic, or crosslinked polyethylene. The counterweight, lifting, and mooring equipment are fitted to a steel rod that extends through the buoy. The 5th class buoy weighs 150 lbs. and the 6th class weighs 85 lbs. The design service life for both is 6 years.

The buoys performed extremely well in service. They proved very easy to handle and required no maintenance. The initial cost is about one-third to one-fifth that of the steel buoys and the service and maintenance costs are negligible. Consequently, a significant economic benefit has been realized through the use of these buoys.

RECOMMENDATIONS:

As a result of this project, it was recommended that these plastic buoys continue to be used in place of the same size steel buoys in environments where ice conditions are not expected. The buoys have been incorporated into the USCG Aid to Navigation System as 6 CPR, 6NPR, 5 CPR and 5 NPR buoys.

PERFORMING ORGANIZATION(S):

USCG

KEY PERSONNEL:

P.J. Glahe (USCG)

REFERENCES/SOURCES:

The reference related to this project may be found under entry number 153 in Appendix B.

PROJECT SUMMARY NO. 8

SECOND CLASS PLASTIC BUOY PROJECT

DATES: 1972 to 1973

OBJECTIVE:

The purpose of this effort was to develop a lightweight replacement for the 2700 lb. 2 CR unlighted steel buoy in use by the Coast Guard.

APPROACH:

The design of the buoys centered on producing a CAN and NUN version using plastic and foam material. Special attention was paid to construction in the upper portion of the buoy in order to save topside weight.

Thirty of the designed buoys were procured and distributed around the U.S. for operational evaluation for a period of one year.

RESULTS AND CONCLUSIONS:

The designs that resulted from this effort (2 CPR and 2 NPR) are 45" Diameter, 1125 lb. buoys consisting of a 3/8" FRP hull filled with polyurethane foam. An internal steel rod runs through the length of the buoy to which the counterweight and mooring hardware are attached.

Operational testing showed that both the design and construction of the buoys were poor. The junction of counterweight tube and buoy body was damage-prone and the foam tended to saturate with water admitted through the damaged areas, as well as through cracks that formed in the shell material. The hollow daymark also had a tendency to flood and heel the buoy over. On the positive side, the buoys were easier to handle due to their light weight and performed better in currents due to their smaller underwater shapes.

The cost of these buoys was much more than that of the steel buoys and it was judged that a steel buoy could be produced that had most of the advantages of the plastic buoys at less expense.

RECOMMENDATIONS:

Due to the high cost and amount of design modifications necessary to make this buoy acceptable, it was recommended that further effort in this size of buoy be abandoned.

PERFORMING ORGANIZATION(S):

USCG

KEY PERSONNEL:

P.J. Glahe (USCG)

REFERENCES/SOURCES:

The reference related to this project may be found under entry number 153 in Appendix B.

PROJECT SUMMARY NO. 9

LIGHTWEIGHT LIGHTED DISCREPANCY BUOY PROJECT

DATES: 1971 to 1976

OBJECTIVE:

The objective of this project was to develop a buoy (or buoys) that would best fit the U.S. Coast Guard requirements for a temporary floating aid. The initial requirements were that the buoy be equipped with a light signal and be of lightweight construction so that it may be easily handled by Aids To Navigation Teams (ANTs).

APPROACH:

The first step in this project was to develop a set of Tentative Operating Requirements (TOR) to form a basis for the buoy design. Requirements were developed for two environmental conditions: sheltered and exposed/semi-exposed. The expectation was that a separate design would result for each of these environments. A literature search was also performed to gather as much data as possible on buoy designs already available.

The second step in the project was to study the available buoy designs and evaluate them with respect to the TOR in order to determine design changes which may then be incorporated into pre-prototype designs. The buoys evaluated in this part of the project included three generations of small foam plastic and aluminum buoys, an aluminum catamaran type buoy for exposed locations, and two buoys which expanded on older discrepancy buoy designs.

After reviewing the performance of these buoys, two pre-prototypes were designed and constructed. The buoys were deployed at several Coast Guard R&D Center test sites and run through a battery of performance tests. These investigations tested stability with inclining, self-righting, and pitch/roll tests; current riding ability both in the field and in a circulating water channel; damage resistance via drop and crush tests; and, finally, operational acceptability through testing with selected field units.

Next a prototype was designed based on the pre-prototype tests. This prototype was a single "wine-glass" shape design for both sheltered and exposed locations. The prototype buoys were procured, tested, and run through operational evaluation. Testing and evaluation of the two pre-prototype designs was also continued.

RESULTS AND CONCLUSIONS

Three buoys were developed that closely fit the requirements for a temporary floating aid. Sheltered and exposed location buoys were based on the two pre-prototypes, both having an ABS plastic floatation collar, free-flooding central tube and aluminum daymark. The third design is the Wine-Glass Discrepancy Buoy (WGDB) applicable to both exposed and sheltered locations. The buoy hull is foam-filled with a rotationally cross-linked, high density polyethylene shell. The daymark is interchangeable (CAN or NUN), and is of aluminum construction.

The WGDB buoy best fits the Coast Guard requirements for a temporary aid because it is the most durable and easiest to handle of all the buoys tested; it costs about half as much as the other two buoys that resulted from the project; its performance in current is superior; it meets the exposed water TOR with the exception of daymark range, radar range, and servicing interval; and it is compact and easily transportable.

RECOMMENDATIONS:

The primary recommendation that came out of this project was that the WGDB should continue to be tested and implemented as a standard lighted discrepancy buoy for USCG use. Since the conclusion of this project, the buoy has become the standard discrepancy buoy for the U.S. Coast Guard.

PERFORMING ORGANIZATION(S):

USCG Research and Development Center

KEY PERSONNEL:

W.E. Colburn (USCG)
W.R. Thompson (USCG)

REFERENCES/SOURCES:

References related to this project may be found under the following entry numbers in Appendix B: 18, 83, 107.

PROJECT SUMMARY NO. 10

5 x 9 LPR BUOY DEVELOPMENT

DATES: 1970 to 1972

OBJECTIVE:

The purpose of this effort was to design a lightweight replacement for the lighted steel 5 x 11 LR buoy. In the design of this buoy, the servicing concepts and test experiences which came out of previous design efforts (see the the CANUN buoy project description) were to be utilized.

APPROACH:

The buoy was designed utilizing plastic and foam construction to achieve light weight. Secondary bonds on the hull were avoided in view of the leakage and cracking problems associated with the previously designed CANUN buoy and efforts were directed toward clamp-on mooring and counterweight hardware.

Six of the buoys were then built and deployed for testing. The areas in which they were tested were not subject to ice conditions.

RESULTS AND CONCLUSIONS

The buoy designed in this project was constructed of a 1/2" FRP shell with an FRP internal framework and a hull filling of polyurethane foam. The daymark was an interchangeable CAN or NUN shape with an aluminum frame and radar reflector. The total buoy weight was 1250 lbs.

The tests showed that the buoy performed very well as an aid to navigation and the materials proved sufficiently resilient. The handling of the buoy proved to be about he same as the steel buoy it was designed to replace.

The cost of the buoy, however, was significantly higher than that of the steel buoy (about 4 times higher using 1979 estimates). Also, the design life of these buoys is less than that of steel buoys.

RECOMMENDATIONS:

The recommendation that came out of this project was that since the cost of the large lighted plastic buoy is so high, it should not be used as a replacement for the 5 x 11 LR. Efforts could be directed, however, toward simpler unlighted buoys.

PERFORMING ORGANIZATION(S):

USCG

KEY PERSONNEL:

P.J. Glahe (USCG)

REFERENCES/SOURCES:

The reference related to this project may be found under reference number 153 in Appendix B.

PROJECT SUMMARY NO. 11

CANUN BUOY PROJECT

DATES: 1968 to 1970

OBJECTIVE:

The purpose of this project was to design a large lightweight buoy to replace the 8 x 26 LR lighted steel buoy and as a possible replacement for the first class unlighted buoy.

APPROACH:

The first task of this project was to design a prototype buoy. Because the buoy was required to be lightweight, the design centered on plastic and foam hull materials.

Once a prototype had been developed, fifteen of the buoys were manufactured and subjected to testing over several years. These tests included evaluations of ease of service and performance of the hull material.

RESULTS AND CONCLUSIONS:

The final buoy configuration consisted of a 3/4" fiberglass-reinforced polyester (FRP) shell filled with polyethylene foam and strengthened by an internal FRP framework. The hull was interchangeable with either a CAN or NUN FRP daymark (hence the description CANUN) and an aluminum radar reflector. The total weight of the buoy was 4250 lbs.

Testing of this design revealed several problems. First, the FRP hull proved to be inadequate, showing signs of delamination during handling, low abrasion resistance and a tendency to leak at secondary bonds and at hull penetrations. The waterplane area was too small for a man to board the buoy for servicing, thus the buoy had to be lifted on the deck of the tender where it proved awkward to handle. There appeared to be no handling advantage gained by using this buoy over a steel buoy.

Although the buoy itself proved to be an unsatisfactory replacement for the steel buoys, the most important result of this project was the recognition that small boats could be used to perform above waterline maintenance and thus the actual buoy weight may not be as critical as the weight of individual components.

RECOMMENDATIONS:

The recommendations that came out of this project were 1) the new service concept using smaller boats should be investigated and 2) the results of the CANUN buoy tests should be used in the design of a future large plastic buoy.

PERFORMING ORGANIZATION(S):

USCG

KEY PERSONNEL:

P.J. Glahe (USCG)

REFERENCES/SOURCES:

References related to this project may be found under the following entry numbers in Appendix B: 23, 153.

PROJECT SUMMARY NO. 12

EVALUATION OF PLASTIC VS. STEEL FOR BUOY HULLS

DATES: 1968 to 1970

OBJECTIVE:

The purpose of this study was to determine if the U.S. Coast Guard should use plastic in lieu of steel for the construction of navigation buoys. If so, the study should determine what steps should be taken to achieve the conversion.

APPROACH:

The first step in the project was to review the existing data on plastics and navigational buoy construction and operations. In accomplishing the latter, buoy inspection, service, and relief operations were observed and key personnel were interviewed.

Next, the technical and operational feasibility of plastics as buoy hull materials was evaluated based on 1) the type of buoys used, 2) buoy relief requirements, 3) environmental conditions, and 4) maintenance and support.

The third phase consisted of a comparison of life-cycle costs of plastic versus steel buoys, and an analysis of total acquisition and support costs. This analysis also included a comparison of plastic and steel with current maintenance schedules and facilities, under improved schedules, and with both improved schedules and facilities.

RESULTS AND CONCLUSIONS:

The results of the study show that the use of plastic for navigation buoy hulls is technically feasible and that plastic buoys can be as or more effective than traditional steel buoys as aids to mariners. It was also found that it is possible to design and manufacture plastic buoys efficiently. Almost all environmental conditions excluding ice service can be accommodated with plastic hulls. Use of plastic hulls can also result in smaller, less costly support vehicles The economic evaluation showed that plastic buoys are economically comparable to steel buoys in terms of total annual cost if present servicing schedules are maintained.

RECOMMENDATIONS:

The project resulted in the following recommendations:

1) The Coast Guard should use plastic for navigation buoys.

2) Future support vessel designs and modifications to present designs should be based on the needs of plastic buoys.

3) A group should be established to oversee the development of plastic buoys.

4) Additional cost savings should be pursued by reducing buoy servicing frequency for both plastic and steel buoys.

PERFORMING ORGANIZATION(S):

Booz-Allen Applied Research, Inc., Washington, D.C.
(Contract No. DOT-CG-90506-A)
USCG (Sponsor)

KEY PERSONNEL:

J.F. Wing (Booz-Allen)

REFERENCES/SOURCES:

The reference related to this project may be found under entry number 144 in Appendix B.

PROJECT SUMMARY NO. 13

NUMERICAL MODEL OF SHALLOW WATER BUOYS

DATES: 1978 to 1981

OBJECTIVE:

The purpose of this effort was to develop a method for the analysis of the dynamics of a typical Coast Guard buoy moored with a synthetic line in shallow water. The intended future use of this method is to 1) determine the cost savings of switching from chain to synthetic line moorings, 2) develop a field design manual for non-engineers, and 3) assist engineers in cases where field designs are ineffective.

APPROACH:

The first step in this project was to conduct a literature search to identify any existing models which may analyze the problem. The next step was to gather preliminary data to form a basis for evaluation of the models. To this end, model tests were performed on towed buoys in waves at Oregon State University's wave research facility. These tests measured the force at the anchor as well as pitch and heave acceleration, for three different standard USCG buoys, one of which was an 8 x 26 hull.

The various frequency domain models were evaluated in light of the test data, but it soon became apparent that the assumptions involved in these models did not fit the operating profile for U.S. Coast Guard buoys. Therefore, the investigation effort turned to evaluating time domain models.

A suitable time domain method was selected and implemented in a computer program. The appropriate input data were developed for the buoys that were tested in the model tank and the computer model was run. The output of the program was then compared to the experimental results.

RESULTS AND CONCLUSIONS

The analysis model selected was a two-dimensional lumped mass system using linear spring elements and empirical damping. This model was originally developed by J. Nath for the National Data Buoy Office. It was found that for the lengths and tensions considered the mooring line could be modelled as a single linear spring. Even so, the program proved very sensitive to the elasticity of the line and it was apparent that for other situations, the line model would have to be refined. The wave theory used in the program was also in doubt because it could not be determined if it matched the waves generated in the tank. Furthermore, because the model operates in the time domain, it would be extremely difficult to apply the program to random seas. The worst problems were caused by the discrete time steps used by the program. The only solution to the problem is to reduce the time steps, which increases program run time and costs.

Overall, the results were encouraging over a fairly broad range of operating conditions, but the model tended to over-predict peak line tension for low mean tension cases and under-predict at high mean tension.

RECOMMENDATIONS:

Upon evaluation of the program it was recommended that the mooring line be modelled as a finite series of linear springs rather than as a single linear spring in order to give a more accurate representation. Also, it was recommended that further work be done with a variety of synthetic line types. A more accurate non-linear wave stream function could be used with the program, although it would increase costs and run time.

PERFORMING ORGANIZATION(S):

USCG R&D Center

KEY PERSONNEL:

D.H. DeBok (USCG)
S.F. Roehrig (USCG)

REFERENCES/SOURCES:

The reference related to this project may be found under entry number 176 in Appendix B.

PROJECT SUMMARY NO. 14

Buoy Motion Prediction Project

DATES: 1975 to 1976

OBJECTIVE:

The purpose of this effort was to determine the response amplitude operators (RAOs) for a U.S. Coast Guard 8 x 26 buoy using two different methods: 1) a statistical determination using recorded at-sea data and 2) a step response determination based on simple dock-side tests. The primary goal of the project was to determine if buoy motion RAOs could be obtained and used to accurately predict buoy motion responses. This prediction capability would allow buoy designers to quickly compare alternative designs and to evaluate lighted buoy detection probabilities.

APPROACH:

In order to obtain data for the statistical RAO determination, several standard 8 x 26 buoys were placed in a "buoy test farm" 13 miles off Cape Henry, VA in 50 feet of water. Instrument packages aboard the buoys recorded pitch, roll, and heave motions while wave heights were measured on a wave gauge mounted on the nearby Chesapeake Light Station. Data was recorded for thirty minutes every four hours.

The step response data collection was performed at dockside at the U.S. Coast Guard base at Portsmouth, VA. Pitch, heave, and roll responses for prescribed initial displacements were recorded, using the same buoy instrumentation as in the statistical tests described above.

The buoy RAOs were calculated from the results of the two test programs described above. Because the at-sea response tests were performed with the mooring bridle attachment, an adjustment had to be made to the step response RAOs to account for this difference.

RESULTS AND CONCLUSIONS:

Analysis of the data revealed that both the moored and unmoored buoys were stable linear systems, thus the concept of a response amplitude operator is applicable to buoy motion prediction. The RAOs of the 8 x 26 buoy have been accurately determined and verified by two different methods. The step response technique yielded RAOs that were very close to those calculated using the statistical method. This finding is significant because the step response technique can give RAOs based on simple dock-side tests which are much more economical and much less time-consuming than the long-term at-sea trials needed for the statistical approach. The effect of the mooring could be successfully accounted for in heave, but some refinement is necessary for the effect on rolling response.

RECOMMENDATIONS:

The recommendations made at the conclusion of this project are:

(1) The step response technique should be used to determine response

amplitude operators for axisymmetric buoys.

(2) An effort should be made to adapt the step response technique to non-axisymmetric buoys.

PERFORMING ORGANIZATION(S):

USCG Office of Research & Development

KEY PERSONNEL:

David Price (USCG)
J.T. Tozzi (USCG)

REFERENCES/SOURCES:

The reference related to this project may be found under entry number 195 in Appendix B.

PROJECT SUMMARY NO. 15

BUOY HULL AND MOORING MODEL MODEL APPLICATIONS STUDY

DATE: 1970 to 1974

OBJECTIVES:

The purpose of this study was to modify an already existing buoy hull computer model and apply it to a limited evaluation of existing and proposed aid to navigation designs.

Attempts were made to evaluate and modify the program in the following areas:

1) Simulation of pitch damping.
2) Representation of the dynamic lifting of the mooring chain off the bottom.
3) Representation of shallow water effects.
4) Acceptance of new forms for representation of near-shore wave spectra and spectra derived from real data.
5) Acceptance of buoy coefficients from outside the program.
6) Analysis of an axisymmetric buoy with a half-beam to draft ratio approaching unity.

RESULTS AND CONCLUSIONS:

The primary result of this study was the modification of the National Data Buoy Office (NDBO) Basic Buoy Hull Mooring Simulation program for application to aids to navigation. The pitch damping that was added to the program provides results consistent with model tests on an 8 x 26 buoy. For other buoys, appropriate damping coefficients must be substituted. The program is applicable to conditions with no excess cable on bottom, which appears to cover a broad range of aid to navigation operating regimes. With excess cable on the bottom, the program may be applicable with certain restrictions on RMS wave height. Shallow water effects did not appear significant based on comparison of depths of 25 feet and 50 feet. Finally the coastal wave spectra developed shows a significant shift to higher frequencies when compared to offshore wave spectra.

RECOMMENDATIONS:

Based on the above results, it is recommended that the program be used with the appropriate damping coefficient for the buoy being examined and, in the case of buoys with excess chain on the bottom, the RMS wave height be limited to 2 ft. with depths of 25 to 50 feet and scopes of 1.5 to 3. It is also recommended that shifted wave spectra based on real data be used rather than the mathematical spectra.

PERFORMING ORGANIZATION(S):

Marine Technology System (Div. of Sperry Rand Corporation)
USCG Aids to Navigation Branch, Washington, D.C. (Sponsor)

KEY PERSONNEL:

MTS Staff
Dan Hoffman (Webb Institute)
Dr. J. Breslin (Stevens Institute of Technology)

REFERENCES/SOURCES:

The reference related to this project may be found under entry number 183 in Appendix B.

PROJECT SUMMARY NO. 16

8 x 26 BE (RR) BUOY, 1962 DESIGN TESTS

DATES: 1962

OBJECTIVES:

The purpose of this testing program was to compare the performance of the prototype 1962 version of the 8 x 26 BE (RR) buoy with the older 1952 version bell buoy. The legs of the 1962 version tower are vertical whereas those on the 1952 version are canted. The counterweight tube on the 1962 version is also smaller than the 1952 version and is watertight.

APPROACH:

The new 1962 version prototype and the 1952 model buoys were tested side-by-side for one day in the upper Chesapeake Bay. The tests compared acoustical performance of the bells, period and amplitude of roll, natural vibration transmitted to the lanterns from the bells, radar range, visual range, ease of handling, durability, and watertight integrity of the battery pockets.

RESULTS AND CONCLUSIONS:

The results of the limited testing showed that the acoustical, visual and radar performance of the two buoys was approximately equal. The roll amplitude of the 1962 version was considerably smaller than the 1952 design and the period was slightly longer, thus indicating greater stability. The handling tests showed that the 1962 version tower tended to vibrate considerably when bumped by the tender, indicating that had insufficient lateral stiffness. Also, although the counterweight tube survived handling during the tests, there was doubt that it could survive rough service. Finally, the mooring eye placement made for awkward handling on deck and forced the weight to be concentrated over a small area, resulting in damage to the deck of the tender.

RECOMMENDATIONS

Since these tests ran for only one day, the results cannot be considered completely reliable. It was therefore recommended that the new buoy be evaluated over a long period in actual use. Changes should also be made to the counterweight tube, tower, and mooring eyes to improve handling and damage resistance.

PERFORMING ORGANIZATION(S):

USCG Field Testing and Development Unit

KEY PERSONNEL:

P.O. Chapman (FTDU-USCG)
W.S. Vaughn (EOE-USCG)

REFERENCES/SOURCES:

The references related to this project may be found under entry number 172 in Appendix B.

PROJECT SUMMARY NO. 17

EXPOSED LOCATION BUOY PROJECT

DAT'3: 1980 to Present

OBJECTIVE:

The purpose of this project is to design a special buoy for use in exposed offshore locations where high survivability and superior signalling capacity is called for. The buoy is also intended as a possible replacement for Large Navigational Buoys (LNBs). The signals which this buoy must support include a main light, passing light, electronic horn and a weather package.

APPROACH:

The first step in the design of the prototype buoy was to select the signalling equipment. From the resulting components, the power requirements were determined and the power system was selected. Because of the high relia-reliability and power requirements of this buoy, consideration was given to wave activated turbine generators and solar power generators. Lastly, a buoy hull and structure was designed to house and support the various power, signal and weather systems selected.

Twenty first-generation prototypes were constructed and tested in exposed locations throughout the United States. These tests identified vibration and strength problems with the tower, which led to a redesign of that component.

A second generation of ELB's was designed with increased signalling capability and the elimination of the weather package. These buoys were then tested in areas where weather sensing capabilities were not needed.

Development was then begun on a third generation ELB which could provide both improved signalling and weather sensing. This design is still under development.

RESULTS AND CONCLUSIONS:

The hulls of all of the ELB configurations are conventional in design with a diameter of 9 feet and length of 35 feet. Power is provided by a combination of a wave activated turbine generator and solar panels. The tower of the first generation was constructed of steel pipe and exhibited a very lively motion which, in turn, led to many failures of the weather package. The modification of the tower consisted of additional bracing at the top, and appears to have corrected the problem. Another problem with the buoy is that the extensive weather package reduced the size of daymarks and radar reflectors that the buoy could accommodate, and thus the buoy had a smaller radar image and daytime signal than other buoys of similar size. Overall, however, the modified first generation ELB's were judged successful for their purpose.

The second generation buoys had no weather sensing capabilities, but were fitted with a more conventional tower geometry and incorporated a double biplane radar reflector and a wave activated whistle. The signalling

capability of the buoy proved to be excellent and this design has been used as a replacement for the 9 x 32 LWR and 9 x 38 LWR buoys.

Because of the need for weather sensing capabilities, only the first generation buoys were considered to replace LNB's. They have so far been used as discrepancy replacements for the LNB's but the inferior signal capability has kept them out of general use as a permanent replacement. The third generation buoy may prove to be a more viable candidate in this regard.

RECOMMENDATIONS:

Based on the results of this effort, it is recommended that development continue on the third generation ELB in order to meet the goal of a replacement for the LNB. It is also recommended that the second generation ELB continue to be used as a replacement for the 9 x 32 and 9 x 38 LWR.

PERFORMING ORGANIZATION(S):

USCG Headquarters (GEOE-4B)

KEY PERSONNEL:

K.J. Heinz (USCG)

REFERENCES/SOURCES:

References related to this project may be found under the following entry numbers in Appendix B: 12, 27, 30, 68, 120.

PROJECT SUMMARY NO. 18

UNLIGHTED ICE BUOY PROJECT

DATES: 1981 to 1984

OBJECTIVE:

The purpose of this project was to develop one or more unlighted buoy designs for use as aids to navigation in ice conditions.

APPROACH:

As a first step in the design process, the needs of several Coast Guard districts were surveyed to determine the sizes and features required for ice environment aids. Based on the information collected, 5th class and larger 3rd class unlighted ice buoys were designed. These buoys were patterned after successful 2CS/NS and 3CS/NS buoy designs.

Both buoys were tested with several Coast Guard districts in the winter of 1983/84. Specifications were drawn up for construction of the buoys and a manufacturer was then selected for general production.

RESULTS AND CONCLUSIONS:

The designs which resulted from this project were cylindrical steel spar buoys in both CAN and NUN configurations. The smaller 5CI/5NI buoy is 24 inches in diameter and 98 inches long in the CAN configuration (110 in. for NUN), and weighs approximately 700 lbs. with concrete ballast. The larger 3CI/3NI buoy is 28 inches in diameter and 156 inches long in the CAN configuration (168 inches for NUN) and weighs approximately 1570 lbs. Neither design incorporates a radar reflector.

The results of the field testing were favorable, and, as a result, these two buoy designs were incorporated into the USCG aid to navigation system.

RECOMMENDATIONS:

It is recommended that the buoys designed in this project be used as aids to navigation where an unlighted, non-radar-reflective aid is required in areas subject to ice conditions.

PERFORMING ORGANIZATION(S):

USCG Office of Ocean Engineering

KEY PERSONNEL:

P.J. Glahe (USCG)
C.B. Doherty (USCG)
L.R. Lomer (USCG)

REFERENCES/SOURCES:

The reference for this project: entry number 66 in Appendix B.

PROJECT SUMMARY NO. 19

6 x 16 LI AND 7 x 20 LI ICE BUOY PROJECT

DATE: 1979 to 1984

OBJECTIVE:

The purpose of this effort was to develop a standard, inexpensive, easily manufactured ice buoy.

APPROACH:

The basic design approach for this ice buoy centered on a "push-down/pop-up" philosophy where the buoy would submerge in moving ice, then right itself and continue functioning after the ice has passed. Such an approach would require a high righting moment for the buoy. A "ride through" approach was dismissed as requiring too massive a buoy and too strong a mooring to be practical. The design also sought to provide a new way to protect the lantern and utilize rugged materials in order to prevent damage. The above-waterline surface was designed to be smooth and minimize the accumulation of spray ice. Finally, the cost of the buoy was kept as low as possible because the loss rates were expected to be high.

Two prototypes of the design that resulted from the above considerations were constructed and deployed first in the upper Chesapeake Bay and then in the Straits of Makinac on the Great Lakes. Operational testing was performed on the buoys during the winter of 1979. Based on these tests, 125 buoys were built and used as winter aids.

Based on operational experience with the first buoy design, a larger version was designed to better handle moving ice in large open bays. Thirteen of these were produced and deployed for evaluation in the 1982/1983 and 1983/84 ice seasons. The heaviest ice occurred during the latter period and several design modifications were made to increase strength and reduce buoyancy. The modified buoys were then tested in the 1984/85 ice season.

RESULTS AND CONCLUSIONS:

The first buoy design (6 x 16 LI) was 2 meters in diameter and 4.8 meters long. The hull is constructed of steel plate rolled into a cone around a central pipe. The deck is also conical, sloping downward to prevent water and ice accumulation. The lantern is mounted atop the upper portion of the pipe extending from the deck and is protected by a Lexan dome. This dome provides no lensing for the light, so the visual range is less than for a normal environment lighted aid to navigation. This arrangement, however, provided excellent protection for the light.

Initial testing of these buoys showed that they performed very well. They proved easy to handle and rode well in the water. They submerged and held station as expected and the Lexan domes protected the lantern very effectively. Operational experience later showed that in large open bays, they were sometimes too easily submerged by moving ice. This prompted the design of the larger 7 x 20 LI buoy which had additional buoyancy.

The 7 x 20 LI ice buoy was 2.1 meters in diameter and 6.1 meters long. Aside from the dimensions, the design is essentially the same as the 6 x 16 LI except that the center tube is replaced by upper and lower pipe sections which do not continue through the hull. The paint on these buoys is a special, very hard coating designed to resist abrasions caused by contact with the ice. Testing of this larger buoy design showed that the buoy actually had excess buoyancy, which prevented the buoy from submerging and caused the ice to drag it off station severely damaging the hull. The design was subsequently modified to reduce the buoyancy and stiffen the hull. Seven of these modified buoys were procured for service as winter aids.

RECOMMENDATIONS:

It was recommended that since these two buoys designs have been shown to work well in ice environments, they should be employed by the U.S. Coast Guard as winter aids to navigation. Since the conclusion of this project, the Coast Guard has adopted the 7 x 20 LI buoy as a standard winter aid to navigation.

PERFORMING ORGANIZATION(S):

USCG R&D Center
USCG Office of Ocean Engineering

KEY PERSONNEL:

P. Glahe (USCG)
D.A. Naus (USCG)
K. Heinz (USCG)
D.H. DeBok (USCG)

REFERENCES:

References related to this project may be found under the following entry numbers in Appendix B: 2, 3, 26, 27.

PROJECT SUMMARY NO. 20

GREAT LAKES ICE BUOY DEMONSTRATION PROJECT

DATES: 1973 to 1975

OBJECTIVE:

The purpose of the project was to test and evaluate modified standard Coast Guard aids to navigation to determine their feasibility for use in the Great Lakes during winter navigation seasons.

APPROACH:

Four Coast Guard buoys were modified to increase their survivability in ice. These four were the 5 x 16, 9 x 20, 9 x 32, and 9 x 38 hulls. An additional 16 foot diameter prototype octagonal buoy was also designed and built for testing. The modification made to each buoy consisted of replacing the standard daymark or tower with a lantern affixed to the top of a steel pipe and protected by a steel cage.

The modified buoys were deployed and tested during the winter and spring of 1973, 1974 and 1975. During the 1973 tests, ice conditions were very mild and only limited evaluations could be made. In 1974 the deployments were divided into two categories: operational and observational. The operational buoys were deployed as functioning aids to navigation in various locations. These buoys were photographed by passing Coast Guard vessels and aircraft when opportunities arose and the mooring line loads were measured by tensiometers on the mooring. The observational buoys were deployed at the same location so that all of the designs would be subjected to the same ice conditions. The buoys were then observed and videotaped. As in the previous year, however, very little information was obtained due to limited ice movement.

In 1975, the buoys were deployed again as operational aids in the lower Great Lakes. Again the aids were periodically photographed and ice conditions were recorded. These tests yielded the most information of the project.

RESULTS AND CONCLUSIONS

The modified 9 x 38 and 9 x 32 buoys seemed to perform adequately when moored with a large 12,750 lb. sinker and 9000 lb. STATO anchor. Otherwise, they tended to move off station when overrun by ice. The lantern, paint and battery covers were all prone to damage. The 9 x 20 hull experienced icing on the top of the lantern pole, which listed the buoy severely. In this condition, moving ice tended to ride under it, pulling the buoy off station. The 5 x 18 buoy was also susceptible to spray ice on the body and lantern pole which caused it to list considerably as well. The buoy is submerged easily by 4 to 6 inches of moving ice was very susceptible to damage. As a result, the 5 x 18 buoy was judged to be inadequate for ice season use. The 16 foot prototype performed well but ice accumulation on the deck also caused this design to list badly.

Overall, the buoys tested in this effort proved to have only limited utility in the Great Lakes. The buoys tended to remain on station only with high holding power moorings. The hull configuration proved to have a great

effect on the ability to withstand ice accumulation on the upper structure. Finally, it is clear that success of an ice buoy is highly dependent on the ice conditions at the specific location where it is deployed.

RECOMMENDATIONS:

The following recommendations were made at the end of this project:

1) Improved lantern protection is needed to prevent damage when the buoy is submerged by ice.

2) Buoy hull paint primer should be the same color as the paint because the outer coat tends to rub off when contact with ice occurs.

3) Reflective tape should be used to increase night visibility.

4) Battery covers should be made flush with the hull.

PERFORMING ORGANIZATION(S):

USCG R&D Center

KEY PERSONNEL:

K.R. Bitting (USCG)

REFERENCES/SOURCES:

The reference related to this project may be found under entry number 7 in Appendix B.

PROJECT SUMMARY NO. 21

WAVE ACTIVATED TURBINE GENERATOR PROJECT

DATES: 1973 to 1977

OBJECTIVE:

The purpose of this project was to test and evaluate a wave activated turbine generator (WATG) as a buoy mounted power source.

APPROACH:

The first step in this project was to procure a Japanese made WATG unit and install it for testing in a Tidelands Corp. 8 x 33 fiberglass buoy. The tests were set up to record cumulative current generated, consumed, and discharged with the battery at full charge. The tests were performed at the Chesapeake light station in 71 ft. of water and in the Boston North Channel.

Next, a WATG unit was installed in a standard USCG 8 x 26 LWB. Tests were carried out for one month in the Boston North Channel and in Boston Harbor to measure power consumption and output.

The final step in the project was an economic evaluation of the WATG and a comparison of the life-cycle cost with a standard primary battery.

RESULTS AND CONCLUSIONS:

The WATG proved to be a very durable power source. In two years of testing, only one turbine unit suffered minor damage and most of the other failures reported were due to electrical connections rather than the unit itself.

The WATG was proven capable of supplying sufficient power to operate the optic of a standard 8 x 26 Coast Guard buoy in exposed and semi-exposed locations. The operating life of the unit is about two years with no maintenance, but this may be extended with some simple refinements to watertight seals. The economic comparison showed that WATG has a higher initial cost than primary batteries, but decreased maintenance gives it a lower life-cycle cost.

RECOMMENDATIONS:

1) The WATG should be considered as a supplemental power source for exposed and semi-exposed buoys.

2) Watertight seals on junction boxes should be modified to better prevent salt water intrusion on the electrical connections.

PERFORMING ORGANIZATION(S):

USCG R&D Center

KEY PERSONNEL:

D.J. Hilliker (USCG)
W.E. Colburn (USCG)
J.W. Cutler (USCG)

REFERENCES/SOURCES:

References related to this project may be found under the following entry numbers in Appendix B: 114, 122.

PROJECT SUMMARY NO. 22

EXPLOSIVE EMBEDMENT ANCHOR PROJECT

DATES: 1970 to 1976

OBJECTIVE:

The purpose of the study was to determine the feasibility of using explosive embedment anchors (EEAs) as a method of anchoring small Coast Guard aids-to-navigation buoys for sheltered or semi-exposed environments. It was expected that this anchoring method could be used as a lightweight mooring deployed by a small aids-to-navigation craft.

APPROACH:

The basic concept of the EEA system was to use an explosive charge to fire an anchor from a gunstand into the seabed, thus fixing a buoy on station. The Magnavox company had been contracted to come up with a design and conduct preliminary testing of the system. The Coast Guard then embarked on a long-term testing program of its own using the final Magnavox design. The test program evaluated firing operations, holding power, mooring material, handling requirements, safety requirements, suitability for lightweight anchoring, and overall risk.

RESULTS AND CONCLUSION:

In general, the results of the study showed that, although the EEA could eventually be developed into a useful mooring tool, there were so many problems encountered in the project that it must be concluded that the system does not meet USCG operational requirements. The biggest problem appeared in the area of mooring material. Every material and configuration tested was incompatible with the system and could not meet extended service requirements. Another problem was the unreliability of the triggering system which then required retrieval and disarmament of a live explosive device. Handling and transport requirements also precluded frequent usage of the system. Finally, the cost of the system was very high in comparison with other mooring methods.

RECOMMENDATIONS:

Based on the results of the study, it was recommended that further development of this mooring concept be abandoned.

PERFORMING ORGANIZATION(S):

Magnavox, Inc.
U.S. Coast Guard R&D Center

KEY PERSONNEL:

D.L. Motherway (USCG)

REFERENCES/SOURCES:

The reference related to this project may be found under entry number 128 in Appendix B.

PROJECT SUMMARY NO. 23

DETECTION OF LIGHTS ON ROLLING BUOYS

DATES: 1987

OBJECTIVE:

The purpose of this effort was to assess the impact of buoy motion on the mariner's ability to detect and recognize standard Coast Guard buoy lights. This assessment would include a determination of whether a detection problem existed and, if so, development of a method to quantify it.

APPROACH:

The approach taken in this effort was to experimentally determine the number of light flashes which could be detected on an actual rolling buoy for various distances and observation times. A light was considered detected if the light produced at least 0.67 sea-mile-candela of illuminance during the observation time. An aid was considered recognized if all flash pulses could be detected within two adjacent flash periods.

The actual test consisted of mooring an 8 x 11 and 5 x 11 buoy off Avery Point in Groton, Ct. and recording the illuminance over various time periods and distances. Additional data recorded were RMS roll amplitude, wind speed and wave height.

From the observed data, the probability of detection and the probability of recognition (POD and POR) were calculated and modelled as functions of flash characteristic, lantern divergence, observation time, observation distance, and buoy roll.

RESULTS AND CONCLUSIONS:

The study produced some very enlightening observations on the detection range of rolling buoys. First, during these tests, the detection range (based on 90% probability of detection) was as low as 30% of the published nominal range. Also, the correlation between buoy roll period and flash rhythm significantly influences signal degradation.

In general, significant range degradation resulted even with less than 10 degrees RMS roll amplitude. Also, increasing the vertical lens divergence can increase the detection probability considerably, as can changing the flash characteristic. As expected, detection and recognition probability decreased with increasing distance and decreasing observation time.

Finally, this study resulted in a unique method of determining detection and recognition probabilities of flashing lights on rolling buoys which takes into account observation distance and time, lens divergence, flash characteristic, and buoy roll spectra.

RECOMMENDATIONS:

At the conclusion of this study, the following recommendations were made:

1) The 90% probability of detection criterion should be investigated as a better measure of buoy detection range than the current Nominal Range.

2) Additional data should be collected to extend the results of this study.

3) The effect of increased lens divergence on probability of detection should be examined.

4) The resistance of various buoy designs to motion in a variety of sea states should be investigated.

5) A method to predict POD and POR using the five variables described in the conclusions above should be formulated.

PERFORMING ORGANIZATION(S):

USCG R&D Center

KEY PERSONNEL:

D.M. Brown (USCG)

REFERENCE/SOURCES:

The reference related to this project may be found under entry number 112 in Appendix B.

PROJECT SUMMARY NO. 24

EVALUATION OF STRUCTURES VERSUS BUOYS

DATES: 1968 to 1970

OBJECTIVE:

The purpose of this project was to evaluate the technical, operational, and economic considerations affecting decisions on the use of buoys or structures.

APPROACH:

The evaluation for this task was split into two areas of emphasis: technical and operational considerations, and economic considerations. In the first area, it was necessary: 1) to examine the technical factors that limit the use of structures; 2) to estimate the opportunities to replace buoys with structures;3) to examine the operational effectiveness of structures versus buoys; and 4) to evaluate the maintenance and support requirements of structures versus buoys.

With regard to economic considerations, the life-cycle costs for structures and buoys were analyzed and compared. This evaluation was performed on the basis of both current and improved maintenance schedules. The analysis was also performed for aids operating in exposed, protected/semi-exposed, and fresh water with ice conditions.

RESULTS AND CONCLUSIONS:

Based on the technical and operational investigation, it was found that structures are more effective as aids to navigation than buoys because they provide larger daymark area and a more stable platform for lights. Maintenance requirements are less for structures than for buoys, thus structures allow the use of smaller vessels on a reduced schedule. Environmental considerations such as water depth and bottom conditions as well as traffic density and location permanence may, however, limit the use of minor structures as marine aids to navigation.

The economic comparison showed that for both structures and buoys, the primary cost element is the servicing vessel (about 72 to 87 percent of the total cost). When the servicing vessels are comparable, the life cycle costs of structures and buoys are comparable. Significant cost savings can be gained for both buoys and structures if improved servicing schedules and smaller servicing vessels are utilized. Overall it was found that cost savings can result from a conversion from buoys to structures only if service unit costs are reduced.

RECOMMENDATIONS:

Based on the findings of this project, it was recommended that the Coast Guard encourage the installation of structures instead of buoys wherever conditions are favorable. Also, it was recommended that additional information be obtained to identify ways of improving the efficiency and

reducing the frequency of service to aids to navigation.

PERFORMING ORGANIZATION(S):

Booz-Allen Applied Research, Inc., Washington, D.C.
(Contract No. DOT-CG-90506-A)
USCG Headquarters (Sponsor)

KEY PERSONNEL:

John F. Wing (Booz-Allen)

REFERENCES/SOURCES:

The reference related to this project may be found under entry number 9 in Appendix B.

PROJECT SUMMARY NO. 25

SRA SERVICING SYSTEM STUDY

DATES: 1968 to 1970

OBJECTIVE:

The purpose of this study is to examine the overall support system for U.S. Coast Guard aids to navigation. The study should include a determination of the required shoreside and floating facilities and recommend a program for their acquisition.

APPPOACH:

The approach of this study was to first review the results of two previous Booz-Allen studies: one on steel versus plastic buoys and the other dealing with a comparison of buoys to structures. From these data, an evaluation of potential future aids, servicing units and operating concepts was performed through economic, sensitivity and trade-off studies. Next, the future concepts resulting from the above evaluation were reviewed with Coast Guard district offices to determine their feasibility. From these discussions, three alternative future systems were formulated: 1) a continuation of the present servicing system and schedules, 2) a proposed system utilizing new concepts and a conservative estimate of improved servicing schedules, and 3) a system utilizing new concepts and an optimistic estimate of improved servicing schedules. Implementation plans were then developed for each of these alternatives. Finally, the alternatives were compared on the basis of annualized life-cycle cost and funding requirements.

RESULTS AND CONCLUSIONS:

The short range aid (SRA) servicing system that resulted from the above study consists of several features which differ from the current system. First, the system includes a family of lightweight plastic buoys which can be serviced by smaller vessels and crews. The system also calls for a 20% conversion of buoys to minor structures in order to improve both aid effectiveness and servicing efficiency. Thirdly, the proposed system includes a short range aid data program and maintainability analysis to reduce the servicing frequency for all types of aids. The plan also calls for the modernization of existing and construction of new buoy tenders. In addition, specially designed smaller vessels would be constructed to take over smaller servicing tasks. Specially trained aids to navigation teams (ANTs) would be formed to man the smaller craft and would be responsible for aid servicing on a full-time basis. Under this system, routine maintenance would be performed by the ANT teams and the large tenders would only be used for tasks that required lifting of the buoy or large-scale repairs. Lastly, the proposed plan calls for an overall reduction in personnel requirements, allowing manpower to be diverted to other Coast Guard duties.

RECOMMENDATIONS:

Based on the findings of the study, it was recommended that the servicing system outlined above be implemented by the U.S. Coast Guard.

PERFORMING ORGANIZATION(S):

Booz-Allen Applied Research Inc., Washington, D.C.
(Contract No. DOT-CG-90506-A)
USCG Headquarters (Sponsor)

KEY PERSONNEL:

John F. Wing (Booz-Allen)
Robert W. Priest (Booz-Allen)

REFERENCES:

The reference related to this project may be found under entry number 10 in Appendix B.

PROJECT SUMMARY NO. 26

ANTI-FOULING RUBBER COATING FOR BUOYS

DATES: 1966 to 1979

OBJECTIVE:

The goal of this project was to evaluate a new elastomeric, tributylin oxide (TBTO) impregnated covering for buoys. The covering was intended to prevent marine fouling and extend the coating life for buoys from 2 years to 5 years.

APPROACH:

The approach taken in this evaluation was to coat two 5 x 11 LR buoys with the "No-Foul" rubber and put them into service. The first hull was coated by B.F. Goodrich (the developer of the coating) at their facility to enable them to develop and test the application techniques. The coating was put on in sheets, cut to conform to the contour of the buoy and affixed with special bonding adhesives. The second buoy was coated at the Coast Guard Yard using the same staff and techniques as the first buoy.

Both buoys were then deployed in high fouling areas off Key West, Florida. The original deployment time was to be 5 years, but this was later extended to 11 1/2 years when neither buoy showed signs of coating failure after the original test period. At the end of the test, a cost analysis was prepared comparing the "No-Foul" coating to more conventional vinyl coatings.

RESULTS AND CONCLUSIONS:

The results of the evaluation showed that the elastomeric coating proved to be extremely durable. There was a large discrepancy, however, between amount of fouling on the buoys. The buoy which was coated at the Goodrich facility showed almost no marine growth after 5 years and very little hard growth after 11-1/2 years when it was finally taken out of service (due to mooring arm wear). The buoy coated at the Coast Guard yard, however, showed large amounts of barnacle growth after 5 years. It is believed that differences in curing time might have been the cause of this discrepancy, but that theory was not fully investigated. In both cases, however, the coating itself showed no signs of deterioration, but the TBTO toxicant concentration had been depleted. Once the buoys were taken out of service, it proved very difficult to remove the rubber coating, requiring many more man-hours than conventional paints. It should be noted that during the course of this project, the life of conventional vinyl paints was increased from 2 to 6 years.

The cost analysis was based on a 12 year period with the vinyl coating being replaced after 6 years. The analysis showed that although a 100% increase in service time could be realized, there was a 600% increase in material cost and 1100% increase in labor costs. Thus, the No-Foul coating does not prove cost effective.

RECOMMENDATIONS:

In light of the above conclusions, it was recommended that no further

consideration be given to the material for use on buoys. However, it may be possible to apply it in other areas such as sonar domes.

PERFORMING ORGANIZATION(S):

USCG Headquarters, Ocean Engineering Division
B.F. Goodrich Co.

KEY PERSONNEL:

Theodore Dowd (USCG)

REFERENCES/SOURCES:

The reference related to this project may be found under entry number 149 in Appendix B.

PROJECT SUMMARY NO. 27

ACCORDION BUOY PROJECT

DATES: 1962 to 1964

OBJECTIVE:

The purpose of project ACCORDION was to measure the accuracy with which jet aircraft could maintain assigned tracks across the North Atlantic. The purpose of the ACCORDION buoy project was to develop and deploy an ocean station-keeping buoy to provide a fixed geographic reference position for a surface vessel equipped with an air search radar.

APPROACH:

The design of the ACCORDION buoy began with the formulation of preliminary requirements. These requirements called for a lighted buoy with a radar reflector and a daymark which can be moored in 2000 fathoms of water with minimal watch circle excursion.

The first approach utilized an 8 ft. diameter toroidal hull with a tripod support structure for the light and daymark. The hull was made of fiberglass and was styrofoam-filled. This buoy performed poorly on station, capsizing frequently, presenting a poor radar image, and requiring constant service. It was then decided that a new approach should be tried.

This second approach was to modify a standard Coast Guard buoy to accommodate a light and radar reflector. This modified buoy was then placed on station and put in operation.

RESULTS AND CONCLUSIONS:

The buoy which resulted from the second design effort was a standard Coast Guard 2nd class steel CAN buoy modified to accept a light and radar reflector. The buoy was 4 ft. wide by 20 ft. long and had a mooring composed of two sections of chain connected by a nylon braided line. The upper section of chain was attached to the buoy and a 2500 lb ballast ball while the lower was connected to a 200 lb. Danforth anchor and an 830 lb. ballast ball.

Overall, the buoy was a success as an aid to the ocean station vessel. It stayed on station in seas up to sea state 5 and displayed adequate daymark, light, and radar range. As a result, the Ocean Station Vessel was able to give reliable fixes for the project.

RECOMMENDATIONS:

None

PERFORMING ORGANIZATION(S):

United States Coast Guard
Federal Aviation Agency.

KEY PERSONNEL:

W.E. Foley (USCG)

REFERENCES/SOURCES:

References related to this project may be found under the following entry numbers in Appendix B: 22, 61.

3.0 SUMMARY OF FINDINGS FROM INTERVIEWS

Interviewing the USCG Headquarters and District ATON personnel (in addition to the literature search) was a principal ingredient in the task for the identification of USCG accomplishments in buoy technology development since 1962.

In order to effectively carry this out, a questionnaire was forwarded to interviewees in advance for consideration and completion prior to the interview. A list of the major headings in the interview form is presented under Subtask A-3 in Section 1.4.2.

A total of five Aid to Navigation District Offices (oan) were visited and personnel interviewed with responses resulting from approximately 50 individuals. These five Districts encompass a majority of mainland USCG Districts with responsibilities for navigation buoys. A comprehensive list showing all interviewees and respondees to the questionnaire is given in Table 3. The detailed comments and responses received during the interviews, in most cases as stated by the interviewees, are included in Appendix A in a synopsized form.

In addition to the USCG authorities, personal interviews with a limited number of buoy manufacturers and ATON equipment suppliers were conducted. The responses received from these interviews are also incorporated in Appendix A.

The interview form addresses a number of items aimed at identifying the sources of data. These were fruitful and resulted in the identification of a number of additional data sources for inclusion into the Bibliography.

Two of the questions in the interview form relating to the USCG developpments and the benefits of the SRA system brought forth a unanimous response that the system has been a valuable resource to waterways navigation and that it does address the needs of the mariner. Major accomplishments were achieved since 1962 in the standardization of buoy configurations, new buoy designs, operational procedures, payload equipment, buoy hull materials, solarization, buoy design and selection documentation, personnel training and in modifications to existing buoys to suit changing ATON requirements.

The interview results indicate, however, that certain problems remain with the buoy system and the opinions expressed were that the system must adapt to changing circumstances. The detailed responses, as recorded during the interviews, on "Problems with Current Buoyage" are given in Appendix A. Some of the comments were that a significant amount of maintenance and servicing by seagoing tenders and shoreside industrial groups is still required for buoys. Other comments were related to personnel hazards and difficulties caused by certain buoy hull construction materials and experienced during handling of large buoys on the buoy tender deck. Problems were also mentioned with regard to the susceptibility to damage from severe environment of the mooring systems, solar panels, power cables, etc., and with regard to specific construction details which need design improvements. However, it was stated by most USCG personnel, and observed by the project team, that an ongoing effort exists to continually improve the components of the buoyage system on the basis of problems encountered.

TABLE 3

SCHEDULE OF VISITS AND INTERVIEWS

ACTIVITY	DATE OF INTERVIEW	PERSON(S) INTERVIEWED	END DOC TYPE	PREPARED BY	END DOC NO.
USCG Headquarters G-ECV & G-NSR Wash., DC	11/21/89	Stan Walker LT Richard Boy Chuck Mosher Paul Glahe	SF	Daidola Basar	1.1
R&D Center	10/26/89	R. Walker	SF	R. Walker	1.2
Groton, CT		LCDR M. Millbach Dr. M. Mandler }	SF	Daidola	1.2
NDBC Bay St. Louis, MS	12/13/89	CDR P. Hill } Doug Scaly } CDR T. Colburn}	SF	Daidola	2.0
NATON School Yorktown, VA	01/16/90	CDR B. Hadler LT N. Merkle CWO I. Sexton BMCM Collins	SUM	Basar	3.0
CG District #1 (oan) Boston, MA	11/29/89	CAPT N. Edwards} LT B. Kretz } LT P. Reid } CWO D. Wheaton } Robert Potkay } BMC W. Lockhead} CWO M. Frias }	SF	Daidola	4.0
		CAPT N. Edwards	SF	N. Edwards	4.1
		LT B. Kretz	SF	B. Kretz	4.2
		LT P. Reid	SF	P. Reid	4.3
		R.M. Potkay	Note	R. Potkay	4.4
Industrial Base Governor's Island, N.Y.	11/16/89	LT John Ochs} Bruce Horner } CWO Gesking }	SF	Daidola Basar	4.5
		LCDR W. Schneeweiss	SF	W. Schneeweiss	4.6
		CWO R. Gesking	SF	R. Gesking	4.7
Industrial Base Weymouth, MA	01/01/90	E. Woodside	SF	Daidola	4.8
CG District #2 (oan) St. Louis, MO	12/06/89	CDR W. Kline} CWO T. Reed }	SUM	Basar	5.0
Base St. Louis		LT Daniel May	SF	D. May	5.1

ACTIVITY	DATE OF INTERVIEW	PERSON(S) INTERVIEWED	END DOCUMENT TYPE	PREPARED BY	END DOCUMENT NO.
CG District #8 (oan) New Orleans, LA	12/13/89	CAPT R. Heym } CDR C. Bohner } LT J. Fidaleo } LTJG K. van Horn} BMC S. Smith } BMCS R. Hunsaker}	SF	Daidola	6.0
		CDR Bohner	SF	Bohner	6.1
Buoy Depot Mobile, AL	12/14/89	CWO Steve Willmann	SF	Daidola	6.2
CG District #9 Cleveland, OH	12/04/89	CAPT Leo Tyo } LCRD T. Briggs} LT A. Sanchez } William Craig } QMCS W. Andres}	SF	Basar	7.0
		William Craig	SF	W. Craig	7.1
CG District #13 (oan) Seattle, WA	12/08/89	CDR S. Norman LCDR C. Cozby BMCS J. Barberi William Craig	SUM	Basar	8.0
Woods Hole O.I. Falmouth, MA	11/28/89	Henri Berteaux Peter Clay	SF SF	Daidola Daidola	9.0 9.1
Bahr Tech. Inc. Madison, WI	12/05/89	Linn Roth Linn Roth	SUM SF	Basar L. Roth	10.0 10.1
Benthos, Inc. N. Falmouth, MA	11/28/89	J. Rezzo } K. McCarthy}	SF	Daidola	11.0
Tideland Signal Corp. Houston, TX	12/12/89	Harry Saenger	SF	Daidola	12.0
Automatic Power Inc Houston, TX	12/12/89	D. Adams } I. Garabieta}	SF	Daidola	13.0
Maritime Consultant		VADM R. Price	SF	Daidola	14.0
Gilman Corp. Gilman, CT	01/10/90	R. Gilman G. Greider		Daidola	15.0

LEGEND
SF - Filled-in Survey Format
SUM - Summary of Findings During Survey/Interview
NOTE - Random Comments Provided by Respondees

Comments were also received from the persons interviewed on suggested improvements to the current buoy systems. Again, a detailed synopsis of such comments, as recorded, is presented in Appendix A. One of the noteworthy suggestions was related to the use of new materials for buoy hulls (such as composites, new grades of aluminum, and other non-corrosive but durable materials) in order to make the buoys self-sufficient and relatively maintenance free. Recommendations were made to improve ice buoys so that they provide a better daymark but present minimum exposure to ice. Increasing the flotation and improving the damage stability of buoys to reduce losses due to sinking was also recommended. The deployment of Articulated Beacons in waters up to 300 feet depth was recommended on the grounds that they were successfully deployed in the LOOP[1] system and that some foreign countries are currently using them with very good results. Among the many other comments were such suggestions as making the topmarks and solar panels integral with the buoy hull to allow easier handling and to reduce the risk of damage to or theft of these components; expanding the use of foam buoys to a greater number of lighted buoy applications; fabricating the buoy counterweights in pieces and joining them together as necessary to improve constructability, etc.

The comments and recommendations on new or advanced buoy technology received from USCG personnel and some manufacturers tended to dwell mostly on the same recommendations given in response to "Improvements" as discussed above. Some of the additional advanced technology recommendations were:

- Investigate the feasibility of designing "small waterplane area twin hull (SWATH)" or catamaran buoy platforms for use in severe ocean environments;

- Design inflatable buoys for use in quickly marking the danger areas;

- Incorporate advancements in solar power technology into buoy designs.

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[1]Louisiana Offshore Oil Port; see Bibliographic Reference No. 32.

4.0 Analysis of Findings

4.1 General

Sections 2.0 and 3.0 of this report along with Appendices A, B and C present the complete findings of the literature search and interviews. The principal objective was to provide a descriptor of data sources and personnel experiences in their entirety.

In this Section, these databases have been subjected to a comprehensive screening for further R&D or improvement. Section 4.2 presents the results of this analysis based on the literature review and Section 4.3 presents the results based on interviews. In Section 4.4, the six problem areas identified by the USCG in the Solicitation for this project are discussed in light of the findings.

All suggestions for further R&D or improvement presented in Sections 4.2, 4.3 and 4.4 will be considered in Task C of this project - "Formulation of Recommendations for the Development of Improved to Aid to Navigation Buoys for the USCG."

4.2 Further R&D Suggested by Literature Review

Through the review of literature, a number of areas were identified where R&D or development have not necessarily resulted in a final or optimum solution. these areas consist of the following:

- o River Buoys
- o Large Lightweight Buoys
- o Articulated Beacons
- o Correlation of Vessel Size to Buoy Characteristics
- o LNB Replacement
- o Measure of Buoy Effectiveness
- o Unlighted Sound Buoy

In the subsections that follow, each of these areas is discussed in more detail.

4.2.1 River Buoys

The Coast Guard has not yet been able to develop a survivable, low cost, lightweight buoy for use in fast water environments. A plastic, fast-water buoy with a hemispherical, foam-filled hull has been developed which rides very well and meets its weight requirements, but its susceptibility to damage and high initial cost has relegated it to only limited use (See Project Summary No. 6 in Section 3.0). Collision and debris accumulation appear to be the most troublesome areas in this type of service, and so far no Coast Guard effort has been able to overcome them. Foam buoys appear to be attractive for this type of service, but the problem of cost and debris accumulation still exists. As manufacturing processes and materials have improved, the costs for these buoys have steadily declined, but, there appears to be no solution in sight for the debris problem. As it stands now, the Coast Guard uses small steel, foam-filled buoys on a throw-away basis for most of its river ATON applications.

4.2.2 Large Lightweight Buoys

Numerous attempts have been made to apply the use of plastic materials to large buoy applications with only partial success (See Project Summaries Nos. 3 to 5 and 7 to 11 in Section 3.0). Large plastic hulled foam-filled buoys were found to be unacceptable as lighted aids, and only marginally acceptable as unlighted aids. This was due to a lack of strength in the plastic and the very high cost of these buoys. Foam buoys have been produced in larger sizes (up to 2nd class as reported in the literature) and even been successfully fitted with solar panels and lighting sets on a test basis. Historically, the major drawback has been the high initial cost of the buoys, which has forced them to be used only in small sizes and in areas where high steel buoy maintenance costs would offset the initial cost of the foam buoy. As in the case of river buoys, declining manufacturing costs are making foam a more attractive option.

4.2.3 Articulated Beacons

Although significant strides have been made in the development of articulated structures, the models that have been developed so far have limitations and deficiencies which preclude their use in many cases. The most troublesome problems are in the area of hardware strength. Originally these type of structures were thought to be able to withstand collision better than buoys. In practice, however, the beacons have proven to be much less damage resistant than expected. Much of this problem has been traced to inadequate strength in connecting flanges and the hinge. Redesign has strengthened these components. The lower hinge is now the most serious problem, still constituting the weak link in the structure and subject to excessive wear. Furthermore, current designs provide an inadequate signal in high currents because of excessive tilt. Lastly, these structures can only be used in up to 60' water depths and 5 ft. tides. The working depth will have to be increased if there is any hope of replacing larger offshore and coastal buoys with articulated structures. The USCG's latest effort is to design another generation of AB's which are extremely effective in protected harbors, semi-exposed locations and open seas (See Project Summary No. 1 in Section 3.0).

4.2.4 Correlation of Vessel Size to Buoy Characteristics

The prevalent factor in support of lighter weight buoys is the effect on servicing vessel size which, it is presumed, will decrease. Although it is true that lighter weight buoys would require less lifting capacity, whether this would translate into smaller vessel size is another question. For example, transporting of the lightweight or heavier buoys may require the same deck area but lighter weight buoys might have livelier motions thereby necessitating a more stable vessel to service them. Also, seagoing tenders may have to retain their dimensions because of the need to operate in an exposed seaway or to carry out other functions and missions in addition to buoy tending. Before any conclusions can be drawn, the effects of buoy characteristics on buoy tender design would have to be evaluated.

4.2.5 LNB Replacement

It has been widely held in the USCG that it may be possible to replace some or all of the Large Navigation Buoys with specially designed minor aids. Although the LNB's have proven very cost-effective relative to the lightships

that they replaced, they are still rather costly aids to construct and maintain. If these major aids could be replaced with minor aids, a substantial cost savings could result. The project undertaken to this end was the Exposed Location Buoy (ELB) project utilizing a standard USCG 9'x 35'buoy hull. The design which resulted from the project proved to be a very effective minor aid but, due to configuration constraints, it proved to be inadequate as a complete replacement for the high-capability LNB. Additional design efforts must be made to approach LNB capabilities with a smaller buoy. A synopsis of further development efforts on the ELB are presented in Project Summary No. 17 in Section 3.0.

4.2.6 Measure of Buoy Effectiveness

The USCG does not have a set measure of effectiveness for its buoys. A series of studies were performed in the early 80's using a simulator to measure the effectiveness of buoy systems and positional configurations, but not for buoy platforms themselves. Some studies have been made on rolling buoy light recognition but still, no measure of merit has been developed. One approach that has been proposed is to measure a buoy's effectiveness in terms of how many days the aid is functioning properly out of a year. This is, in effect, a measure of availability rather than a measure of how well the aid performs as a guide to mariners. It therefore appears that the USCG still needs to develop a measure of effectiveness which takes into account both aid availability and efficacy, so that new buoy designs may be compared to existing ones. Task C of the current study will expand on this subject.

4.2.7 Unlighted Sound Buoy

The two major flaws of the current wave-activated sound buoys are that they are relatively heavy and their sound signals have a range of only about 1/4 mile. A new unlighted sound buoy is needed with decreased weight and increased range. Bibliographic Reference No. 32 states that the USCG will develop a new sound signal buoy design, predict the performance characteristics, construct and deploy a prototype buoy using actual design criteria as follows:

- 20 to 300 ft. water depth
- 85lb bell and two 60lb gongs with stand
- 6 year service life for buoy and mooring
- unit cost of about $8,000.

The "New Buoy Systems" program will include this approach as well as alternatives such as bringing back the 9 x 20 buoys with some modifications.

4.3 Improvements Suggested by Interviews

A comprehensive effort has been made to derive a list of suggestions from the interviews implying further R&D and improvements. These have been grouped under the following major categories in an effort to identify broader areas where study is needed to solve current problems or develop improvements for the future:

- o Buoy Hull Design
- o Construction Materials
- o Payload and Equipment

- o Improvements to Existing Buoys
- o Standardization

In the subsections that follow, each of these will be discussed in more detail.

4.3.1 Buoy Hull Design

4.3.1.1 General

The improvements in buoy hull design suggested by the interviews can be subdivided into three categories:

- o Improvements to Existing Buoys
- o Development of New USCG Designs
- o Adoption of Non-USCG Buoys used worldwide

The subject of improvements to existing buoys is dealt with in Section 4.3.4 below. The remaining two areas are considered in the two sub-sections which follow.

4.3.1.2 Development of New USCG Designs

The suggestions regarding the development of new USCG designs primarily related to components of the buoy which might require a new hull design or to the development of a new hull to adequately meet operational requirements. A listing of these follows:

- o Spar buoys as winter markers may offer an improvement in station-keeping under the action of ice forces.

- o Buoys designed/built with adequate damage stability will be able to better withstand the effects of hull penetration. In steel buoys, this may be accomplished by compartmentation or by filling with buoyant materials.

- o Surlyn foam technology is continually advancing and already provides the ability to construct a wide variety of buoys. The basic building block is a cylindrical roll of Surlyn which can be made in varying diameters and can later be shaped to any configuration. The central core is usually steel and this may be the weakest link since it will corrode.

- o Buoys could be designed at the outset for solar power systems incorporating features for solar panel protection (from bird droppings and from theft), improved battery arrangement for protection, ease of maintenance, and optimum relational location and arrangement of signalling devices, battery, and solar panel. These should be value engineered against existing buoys which have been modified to accept these components.

- o Foam buoys could be considered for a greater number of lighted buoy

applications. A paper[1] to be presented by the USCG to the 1990 IALA Conference states that two approaches to lighted foam buoys were attempted, i.e. a second class can buoy (2CR) and the standard 4 x 11 lighted buoy. Project Summaries Nos. 4 and 5 also discuss these applications.

- o Analysis of buoy motions to determine the effects of shape, mass, and mooring forces is desirable. Project Summary No. 14 reports the findings of a "Buoy Motion Prediction Project" performed in 1975-1976. The recommendations made therein could be a starting point for new R&D efforts. It has been reported that Surlyn buoys have motion in waves which may allow them to be more visible than steel buoys when both are fitted with a light. They can also be designed and easily built to behave in different ways, such as riding on the water in fast current areas and absorbing impact from debris.

- o The use of sectional Surlyn type foam as the main buoy hull with a cage of either Surlyn or a more conventional metallic material could be considered. If "building block" sections could be utilized to make more than one class of buoy then a situation would exist where buoys as needed could be made from stock/inventory material. This should result in a significant economy in manufacturing and inventory.

- o Buoys with foam inside and a tire-like rubber outside to absorb impact may be more resistant to damage from ships and debris.

- o In developing new designs, life cycle cost analyses should be carried out to identify the most cost effective options.

- o Consideration should be given to designing entirely new buoy systems for certain applications. An example which has been considered but never applied by the Canadian Coast Guard was deploying lightweight buoys by simply dropping them from the deck of a catamaran buoy tender through cartridge type storage racks on the tender's deck.

- o Feasibility of designing SWATH (Small Waterplane Area Twin Hull) or catamaran type buoy hulls should be investigated for possible use in severe weather locations.

- o Inflatable buoys could be designed for use in quick marking of danger areas.

- o The buoy design process should follow a systems approach covering all elements of the system including the buoy hull, signals, power sources, and mooring.

- o The utilization of winter stake type spar hulls as ice buoys should be explored so that they can resist being dragged off station by ice. These are currently being utilized in Canada.

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[1] Walker, S.; Boy, LT R.; Strohl, D.; Davis, K.; "Developments in Floating Aids to Navigation".

4.3.1.3 Adoption of Non-USCG Buoys Used Worldwide

During the interviews with manufacturers, a number of navigation buoys were identified that are being supplied to U.S. commercial firms and to foreign governments and companies but not to the USCG. These buoys differ in size, configuration and material and cover a large range of characteristics. To date, only a sampling of buoy manufacturing companies within the U.S. were queried, and subsequently the data presented herein is also limited in scope. The Task B report under this project contains detailed data and illustrations of U.S. and worldwide commercial buoys.

The variety of the navigation buoys available and the success which they have reportedly enjoyed suggests that they are possible candidates for use by the USCG if they offer improvement over existing buoys. A listing of companies having such buoys and a sample listing of their buoys follow.

Automatic Power, Inc.

- Buoyant Beacon (similar to USCG articulated beacon concept) for turning basins and channels
- Lighted/Sound Steel Ocean Buoys, approximately 6'x 20' and 8'x 26'
- Series of short skirt steel buoys approximately 7'X 16' and 3 1/2' x 8'
- Unlighted Steel Buoy (can type)
- Small molded fiberglass buoys
- Gimballed lanterns and other equipment

The Gilman Corporation

- Surlyn buoys for the USCG and a variety of Surlyn foam buoys for other applications

Tideland Signal Corporation

- Flasher Lamp/changers, Racon, and other equipment
- 8' x 21' fiberglass sea buoy
- Approximately 6' x 9' and 6' x 12' fiberglass and foam buoys with integral signalling devices
- Various Steel buoys up to 8' in diameter
- Articulated Buoy with taut moor

4.3.2 Construction Materials

A wide variety of suggestions were made by the interviewed USCG personnel and by the limited number of U.S. buoy manufacturers with regard to buoy construction materials. A brief discussion on the findings is presented in Section 3.0; the detailed comments can be found in Appendix A.

Given in this section is an abridged listing of suggested improvements to construction materials which have been recommended for use in future buoy designs:

a) In general, the use of new or improved construction materials such as composites, new grades of aluminum, and other corrosion resistant and durable materials should be studied.

b) Surlyn foam buoys are currently being used in unlighted and some lighted buoy applications as manufactured by the roll and wrap-around method. Improving the manufacturing process to adopt pouring of foam into a mold or suitability of using rotational molds should be investigated.

c) The feasibility of using poly-vinyl chloride (PVC) or fiber or glass reinforced plastic (FRP/GRP) materials in buoy construction should be established. (PVC buoys are currently in use in the North Sea). The results of worldwide buoy technology review are presented in the Task B report and include PVC as well as FRP/GRP buoys in use in North European countries surveyed.

d) In order to prevent waterlogging of steel foam-filled and hard shell plastic foam-filled buoys, the feasibility of increasing the density of the polyurethane foam or using other alternative materials should be studied.

e) New paint systems may provide coverage for buoys and buoy elements such as solar panels, solving the problems of bird droppings and buildup of marine growth.

4.3.3 Payload and Equipment

The improvements suggested for the buoy payload (visual and audible equipment, batteries, etc.) can be grouped as follows:

f) Making solar panels and topmarks (for lighted solar powered buoys) integral with the buoy hull should be studied.

g) The advantages/disadvantages of changing the shape of battery pockets from round to square and reducing their depth should be investigated. The investigation should also cover the use of an external battery box installed in the cage. Depending on actual success of this battery box in withstanding the environment, the eventual elimination of battery pockets from the buoy hulls (as well as the resulting need for compartmentation or foam filling of the buoy to improve stability and survivability) should be included in the study.

h) Means of improving the solar panel design, fabrication and installation to provide better protection against the environment should be sought.

i) In order to increase radar reflector discernability, the feasibility of using some commercially available reflectors should be looked into.

k) The desirability and cost effectiveness of placing homing devices on buoys in high loss areas to facilitate search and recovery operations should be studied.

l) Similarly, the installation of radar transponders or Loran receivers on buoys in critical areas to accurately monitor their position should be investigated.

m) The recent cracking and breaking cases of the Lexan domes on lighted ice buoys should be studied, the cause determined and a remedy sought.

n) The desirability and cost effectiveness of using electronic bells and gongs (to eliminate possible damage due to shock vibration) in lieu of current mechanical equipment should be studied.

p) An investigation should be undertaken to determine if the wave activated turbine generators (WATG's) are indeed providing power and whether their use on Exposed Location Buoys should be considered reliable and cost effective.

It should be noted that on most of the above mentioned areas (as recommended by the persons interviewed during Task A), the USCG had already initiated investigation efforts as evidenced by the Project Summaries Nos. 3 through 27 presented in Section 3.0. The report for Task C of the current study includes further discussion of on-going R&D projects and establishes the recommendations for further R&D.

4.3.4 Improvements to Existing Buoys

Some of the "materials" and "payload" improvements listed above in Sections 4.3.2 and 4.3.3, specifically (d), (e), (g), and (m), could also be considered as improvements to existing buoys. Other suggestions related directly to the buoy platform were:

- Ice buoys should be improved to provide a better daymark and present minimum exposure to ice.

- Cages should be welded to buoy hulls instead of bolting.

- Counterweights could be fabricated in pieces rather than casting as a single piece.

- Cages could be constructed out of aluminum alloys to reduce weight.

These suggestions (made by various interviewees) should be considered as to the desirability, usefulness , and cost effectiveness of adopting them. Task C Report addresses these and other development recommendations in further detail.

4.3.5 Standardization

The existing USCG ATON buoy stockpile and the equipment installed on them as payload are considered by most personnel to be fairly standard as is. However, a few additional suggestions were made for further standardization:

- o Adding a conical section to the top of the 24" diameter battery pockets so that they can accept standard 22" covers. (One USCG District has already accomplished this modification).

- o Installing an adapter on 9 x 35 whistle buoys to convert them for use as bell or gong buoys with or without a wave generator. This modification was also successfully carried out in one USCG District.

- o Using the results of life cycle cost analyses of buoy designs to identify the most cost effective options and to direct possible standardization efforts to these options.

4.4 Specific Problem Areas Identified by the USCG

In the solicitation for this project, the USCG had identified six problem areas currently existing in the buoyage system. In the sections that follow each of these areas is reviewed and amplifications are offered in light of findings from this study.

4.4.1 Insufficient Cataloging of Buoy Design Information

The USCG desired to develop a compilation of all past information presented in a format useful to design engineers. Accordingly, a principal objective of Task A was to collect all past pertinent information through a literature search/review and interviews of USCG personnel and U.S. experts. This has been accomplished and the information has been synopsized and compiled. It has been presented in a form and format useful to researchers and design engineers as a Bibliography, Abstracts, and Project Summaries. In addition to the hardcopy listings mentioned, a computer database has been developed, as part of Task B, wherein specific data on all types of USCG buoys as well as buoys encountered during worldwide surveys are included in addition to past R&D efforts. Task B Report presents these results in detail. The recommendation that logically follows is to maintain the database by adding the results of any future investigations.

4.4.2 Buoy Relief and Maintenance Cycles

Section 3.0 of this report summarizes and Appendix A gives in detail the responses of numerous USCG personnel regarding problems with the current system. Solutions to these problems will all contribute to extending relief cycles but a few have a greater potential to impact this consideration:

- o Increased floatation and damage stability: Some buoy tenders spend a large amount of time on damage repair. Improved damage stability will reduce such activities.

- o Prevention of bird droppings: This will eliminate the discoloration of buoys and provide better protection for solar panels, if fitted.

- o Increased protection of steel buoys from corrosion: Through the use of new improved paints and other coatings, better materials, and/or heavier scantlings effects of corrosion damage can be reduced.

- o Better anti-fouling protection: This will help reduce buoy sinkage through marine growth buildup. Possibly new ablative paints and

coatings could help shed marine growth. Current paints may be more effective on vessels that move through the water, which will aid shedding of marine growth.

4.4.3 Buoy Watch Circles

The study results have indicated that the USCG articulated beacon has experienced problems with damage to the bottom hinge or universal joint and ice damage to the buoyant float. It has been suggested during the interviews that the bottom hinge problem, attributed to high loading, can be alleviated by the use of a taut-moor which has increased flexibility. One of the manufacturers listed in Section 4.3.1 has such a taut moor beacon which reportedly has had a good service record.

Another possibility for the reduction of watch circle has surfaced during the project. Light synthetic material buoys may be able to utilize chain with less scope. This could also be further investigated.

4.4.4 Buoy Shape Significance

As discussed in Section 3.0 and in Appendix A of this report, all USCG District ATON offices interviewed indicated almost 100% conformance with IALA requirements. Only the mid-channel buoys do not meet the IALA topmark requirement but will in 1990. It should be noted here that, in reality, the U.S. has not adopted all of the aids in IALA's inventory and that the districts have met the IALA standards only to the extent that the USCG headquarters (NSR) has identified for adoption and instructed the districts accordingly. The IALA Maritime Buoyage System, agreed upon by the United States in 1980, included both lateral and cardinal marks. The United States decided to use only the lateral system. Also excluded from adoption by the USCG is the "Isolated Danger Mark".[1]

It is worthy to note that full body foam or GRP buoys have the capability to be designed and configured such that they can meet shape significance without topmarks. This may be considered in future designs.

4.4.5 Optimal Payload Support

The existing aid to navigation buoys in the USCG SRA system have been subjected to many design modifications in order to make them more suitable to installing new and different types of payload equipment. The objective of these modifications and the use of new payload equipment was to improve the performances of the aids in terms of signal effectiveness, servicing efficiency, and survivability, and therefore reduce the life cycle costs.

The buoy platform, i.e. the hull, has to be able to support the payload and provide ease of maintenance and servicing by ATON personnel and by buoy tenders. In order to obtain a superior aid to navigation, the design of the buoy platform should be based on a systems approach to include incorporation of requirements for weight/volume support, maintenance, and servicing imposed by the specific types of equipment to be installed on the buoy, e.g. the

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[1]See Bibliogrphic Reference No. 8 and 43.

radar reflectors, signalling devices, daymarks, topmarks, etc. as applicable.

4.4.6 River Buoy Survivability

In the Western Rivers Region, the USCG currently uses 4th and 6th class buoys. These are unlighted, steel foam-filled buoys. The river environment is harsh; high currents are combined with constantly changing river bottom contours. The buoys are additionally subjected to damage due to collisions with large barge tows and accumulating debris. Consequently, a great number of the river buoys are lost each year. This is one reason why these river buoys are considered "throw away" equipment. Whenever they are lost due to any cause, they are simply replaced by new ones. Obviously, this requires having the necessary numbers of buoys contracted and constructed each year.

During the interviews with USCG Second District ATON personnel, it was learned that approximately 8,000 out of the total 11,000 buoys stationed are lost annually on the average. Even though some of them are recovered through a citizen incentive program, the numbers that have to be replaced are still very high. The current average cost of one buoy, as reported by District 2, is $230 and the cost of deploying replacements is obviously additional.

It can be seen that a great need for improving the survivability of river buoys exists. The USCG has studied the river buoy survivability problem[1] and considered the development of a less expensive buoy of the same design as the 4th and 6th class CAN and NUN buoys but with additional features to increase the survivability of the reuseable portions of the buoy. New construction techniques, such as concrete-foam combinations, were also considered to not only lower the construction cost but also to provide better survivability and increased effectiveness for the Western Rivers buoyage system.

[1]See Bibiographic References Nos. 32 and 59.

APPENDIX A

SYNOPSIS OF RESPONSES FROM INTERVIEWS

The responses received during interviews of USCG personnel are included herein essentially as recorded and without analysis but with an effort to categorize them under the following major subheadings as requested by the USCG:

- Impressions of USCG R&D efforts since 1962
- Problems experienced with current buoyage
- Improvements suggested to current buoyage
- Applicable new or advanced technology
- Impact of conformance with IALA standards

Some of the comments made by the interviewees necessarily overlapped more than one major category and several statements differed from comments made by others. In order to preserve the "authentic" nature of the comments, they were kept intact in most cases, and consequently a certain extent of redundancy and contradiction was unavoidable.

A.1 Impressions of USCG R&D Efforts Since 1962

- The Buoy System is working well; the number of buoys is certainly sufficient to adequately mark the waterways. Reliability is good.

- Materials other than steel were introduced to buoy construction. Foam buoys, plastic foam filled buoys, aluminum superstructures, and GRP buoys were experimented with.

- Radar reflectivity of foam buoys was improved by using internal bi-plane metal insertions.

- Contracting of buoy construction to minority businesses was initiated.

- The articulated buoy was introduced for accurate station keeping.

- The experimental 4 1/2 x 10 lighted buoys were successfully tested.

- A manual entitled "Buoy Mooring Selection Guide - COMDTINST M16511.1" was developed. This publication in part contains the historical design documentation for USCG buoys. It was recognized that the design history over the years was not completely documented.

- In the 1980's, the emphasis on navigation buoys within the USCG was directed more toward managing the system than trying to redesign buoys.

- ANT teams were introduced which operate in semi-protected locations with 55 ft. and under buoy tenders and release the larger buoy tenders for servicing unprotected areas.

- The power needs of lighted buoys were changed from acetylene power to

primary batteries and subsequently to solar power panels with rechargeable lead/acid batteries. Solarization was accomplished with a significant reduction in the amount of batteries required on a buoy resulting in $300/aid/yr savings.

- Swingbolts used on covers of battery pockets were changed to V-Bands, then to swing bolts in combination with V-Bands, and the latest trend is to use 8 or more swingbolts in combination with a knife-edge gasket.

- Short skirt buoys (like the 7 x 17s) allow for vertical stowage on the buoy tender deck, increasing the buoy density and the number that can be carried.

- Lexan domes were used and tested with good results on the new 6 x 16 LI and 7 x 20 LI (Ice buoys).

- Introduction of wave turbine generators and solar panels for exposed location buoy (ELB) resulted in greater capabilities due to available power.

- The 9 x 20 conical base buoy design was considered to be a major improvement for the bell and gong buoys.

- "Throw-away" foam-filled steel buoys were introduced in the Western Rivers region to reduce life cycle costs.

- The majority of USCG developments have been evolutionary in nature. Some characteristics due to old requirements have now been superseded, but the existing designs have not been modified accordingly.

- The system continues to evolve as a working system with an established reliability factor. There are very few user complaints and it is compatible with current servicing platforms and proposed replacement designs.

- Greater thought has been given to standardization of buoys and buoy equipment.

- The elimination of acid batteries which has accompanied solarization has made it possible to avoid a nuisance and a problem. Acid from batteries had been causing injuries to personnel and damage to buoys.

- Welded steel buoys have been as successful as riveted buoys. Further, steel buoys can be repaired on site and this is an important aspect of the current maintenance system.

- Accuracy of buoy stationing has been emphasized because of the liability USCG has experienced regarding the placement of their buoys.

- Buoy tenders are increasingly being used as multi-mission vessels.

- USCG work on buoy motions and the testing accomplished at the Oregon State University offer an approach to buoy design taking into account

motion response.[1]

- o USCG has not taken a systems design approach to the buoy itself including the hull, signals, mooring and power supplies. The approach to purchasing buoys and signals separately precludes this approach to some degree.

- o Plastic buoys of various types have been designed but not necessarily with a well prepared set of specifications for the material.

- o The USCG has continued with bells and gongs, which cause damage to other signal components. Electronic bells are available today and could reduce the problems.

- o Continued use of USCG steel buoys of rugged design is a good approach and has contributed to the success of the system.

- o Foam filling of the 4th and 6th Class buoys used in Western Rivers was a big improvement. Since the buoys are expendable, the reduction in life cycle costs proves to be beneficial. Only minor repairs are done on the buoys. If the damage is major, the buoys are dumped; only the counterweights are saved.

- o Buoy hulls work well for their intended purpose.

- o Data buoys have compartmentation to provide damage stability. For this purpose, they have been foam filled. Repair is difficult and getting rid of the foam also presents an environmental problem.

- o Some changes made in the R & D and design stages don't work well in the field. A better feedback system would be useful.

- o Foreign companies and organizations use buoys similar to those in the U.S. which would lead one to believe that what the U.S. is doing is good.

- o The weak point of the Articulated Beacon (AB) is the universal joint. However, the AB still holds promise for future if this design problem is solved.

- o The AB should not have been designed with two shackles at the nose. The hammering motion caused failures.

- o New foam buoys are more resistant to damage than steel buoys.

- o The standard USCG plastic shell foam-filled discrepancy buoy is a good design and works well; it is lightweight and therefore can be deployed with a small boat without need for a buoy tender.[2]

- o Introduction of plexiglass pyramids provided good protection against

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[1]See Bibliographic Reference No. 167.

[2]See Bibliographic Reference No. 153.

birds.

- Bails (lifting eyes) have been placed outside the buoy hull which makes it easy to see and maintain.

A.2 Problems With Current Buoyage

- Some of the larger (7') ice buoys appear to have too much buoyancy, give too much resistance to the ice, and are ultimately dragged off station.

- IALA topmarks are not desirable. The first set of topmarks did not last very long; then they were reinforced. Still, however, they are difficult to handle and dangerous to work with.

- 6 x 16 Ice buoys provide a poor daymark.

- Short skirt buoys (like 7 x 17s) may be subject to damage to the mooring arms when brought aboard a tender.

- Surlyn foam buoys are subject to ice damage when used for this purpose.

- Surlyn foam buoys require better radar reflectivity

- The steel foam-filled buoys are extremely expensive to maintain and for this reason, they are treated as "throw-away equipment". The current average cost of one buoy is $230 and about 8,000 of them are lost each year on the average. Surlyn buoys would be very good for use in rivers; however, they are expensive for use in such areas where so many buoys are lost per year.

- The shock imparted by gong buoys to batteries and electronic flashers may be causing increased damage to these items.

- Tube sizes were made smaller and this helped reduce costs. However, it could not be inspected for wear resulting in the dropping off of the tube and the counterweight. One remedy is to weld gussets to stiffen the tubes.

- Many faces of lighted buoys result in significant sand blasting time during maintenance and repair.

- Overall the system requires significant maintenance, servicing by both seagoing and shore units.

- Battery changing operations are difficult; handling of the sinkers also prove to be difficult at times.

- Corrosion of steel buoys necessitates frequent maintenance and repair. It is also responsible for loss of buoys.

- o The design history and documentation of USCG buoys is not available.[1]

- o Hardshell plastic buoys with foam filler have not done well. Plastic tends to crack and break, then the foam gets waterlogged.[2]

- o Foam-filled buoys present a personnel hazard when an attempt is made to do welding. The foam, when heated, gives off a toxic gas.

- o The articulated beacons are difficult to service with current buoy tenders.

- o Bolting of the buoy cage to hull proves to be less than optimum. Bolts can be sheared off.[3]

- o On site repair of plastic buoys is not currently possible.

- o Repairs on aluminum NOMAD buoys are difficult.

- o Buoy battery pocket crossover tube tends to get blocked, thereby reducing or prohibiting ventilation and resulting in shorter battery life.

- o On some buoys, tubular cages are used as conduits for wiring. The problem is that when the tube gets hit, the wiring also gets damaged.

- o Electrical contacts with mechanical parts tend to be damaged by shock and vibration imparted to them from the buoy.

- o Conventional LORAN receivers currently available for radionavigation buoys offer limited performance in the following areas: 1) reduced accuracy with no quantitative documentation of signal quality or position reliability; 2) slow acquisition time with attendant reduction in battery life and buoy operation; 3) limited operational range; and 4) unreliable around-the-clock operation. In addition, buoys equipped with conventional LORAN receivers are unnecessarily large, complex and expensive.

- o Buoy mooring systems may be further improved by adopting advancements in recent technology.

- o In very bad weather, the mooring will usually fail first. Solar panels may blow away in a storm. Seagulls may peck at and damage power cables.

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[1]Some historical and design documentation are contained in "Buoy Mooring Selection Guide - COMINST M16511.1".

[2]See Bibliographic Reference No. 32 (Discussion on 2CPR and 2NPR Buoys).

[3]It should be noted that steel buoys are no longer manufactured in this manner. The cage is welded to the hull.

- o Keeping water out of the battery pockets has always been a problem.[1]

- o Providing buoy floatation while avoiding resonances with the environment still represents the most significant problem and challenge. This applies to heave, roll, ice, etc.

- o Some user complaints were received on the green IALA color. It is believed this is only a psychological reaction due to change from black to green.

- o Heavy buoy damage is experienced in the N.Y. Harbor. USCG Sorrel (District #1) is assigned to maintain 144 aids with one visit per aid per year, but because of frequent repair requirements, usually ends up making double the number of visits per year.

- o 9' buoys are hard to handle because of the length of cage.

- o Short skirt buoys can be stacked well on the buoy tender deck, but they are unstable. They are good buoys for what they are intended, i.e. for shallow protected waters.

- o It would be desirable to have four padeyes on larger lighted buoys instead of three for better handling by the buoy tender.

A.3 Improvements to Current Buoyage

- o Integral topmarks would allow easier handling of the buoys with reduced risk of damage. Same is true for solar panels.

- o Design of solar panels should be improved to provide better protection against the environment. The USCG Ninth District (oan) is currently testing a solar powered ice buoy (7 x 20 LI) on which the panel is banded to the neck of the buoy.

- o Current buoy hulls are based on designs originally prepared for acetylene powered buoys. The designs should be changed to suit solar power. A value engineering study on existing buoy hulls to modify or redesign them to suit current requirements, such as solar power, may prove beneficial: the design of bracket attachment for solar panels may be improved, the cage/solar panel design may be integrated.

- o Increased damage stability can be obtained through the use of foam and/or compartmentation. Foam filling of steel buoys will make them more difficult and dangerous to repair, especially aboard a tender. A cost analysis/feasibility study should be conducted to determine if further compartmentation of buoy hulls will prove beneficial.

- o A reconsideration of the battery pockets is necessary. Currently they are round in shape while the batteries are square. Furthermore, they are sized for a greater number of batteries. The battery box atop

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[1]The latest approach of using 8 swingbolts in combination with knife-edged gasket has helped improve this situation.

buoy hull can also be further improved, particularly for protection against cold weather.

- o Buoy battery pockets and covers can be standardized. The top cover can be changed to convert 24" covers to 22" covers by adding a conical section; and in this manner both the 22" and the 24" cover plates can be used interchangeably on all buoy battery pockets.

- o It is desirable to match buoy characteristics to the motion responses appropriate for the intended signal.

- o Cost effectiveness is important. A systems approach to design could be taken.

- o A buoy with marine fender tire like rubber outside and foam inside may prove to be more resilient.

- o An adapter can be used to convert 9 x 35 LWR buoys for use as Bell or Gong buoys, or with a Wave Generator.

- o The possibility of using aluminum cages to make the buoys lighter could be investigated.

- o Adaptation of buoys made by and for others to USCG service should be considered.

- o The ultimate goal should be to design a buoy which can survive collisions with ships.

- o The unions on the battery vent lines on most buoys can be eliminated and the joint permanently welded since there is no case where the tower has to be disconnected except when it is heavily damaged. And if there is heavy damage, it should be just as easy to replace the vent pipe as well.[1]

- o Signal gear should be protected more effectively by better buoy design.

- o The flash provided by the flash tubes does not work as well as hoped for. The flash does not last long enough; some improvement is needed.

- o The views and comments of pilots should be solicited and taken into consideration in new buoy designs and/or modifications.

- o Homing devices should be placed on buoys that have a high probability of being lost provided this can be done cost effectively. In certain critical areas, it may be desirable to install a LORAN receiver to accurately monitor the buoy's position whenever it is deemed necessary to do so. Installing a radar transponder (RACON) on special buoys would be very useful in identifying them with coded signals. This would be extremely valuable in congested areas.

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[1]A design modification has been authorized by the USCG to eliminate these unions and to permanently weld the joint.

- o Conventional radionavigation buoys with transmitters and LORAN receivers have a separate, dedicated controller board that "oversees" data acquisition from the receiver, and subsequent transmission of that data. One U.S. manufacturer has developed a new LORAN receiver which can also assume the role of the controller board, thereby reportedly making the buoy: 1) less expensive - cost of the controller board is eliminated; 2) more reliable - a single unit is less complex and easier to service; and 3) smaller - one board takes the place of two.

- o For buoys in areas of high current, fairing of buoys or added fairing pieces can be introduced to reduce drag.

- o Surlyn type foam may be utilized as the main buoy hull material with a center section connected to a more conventional metallic cage and mooring base. This may cut the weight of buoys in half. In effect, Surlyn simply becomes a floatation device. The layered sections could provide for different amounts of floatation and hence the opportunity to provide for assembly of varied buoys from stock/inventory material. Significant manufacturing and inventory economics may be realized as a result.

- o By increasing the density of the polyurethane foam where it is utilized as a floatation device inside the buoy, water intrusion may be precluded.[1]

- o Taut-line mooring for articulated buoys will preclude high structural forces at the sinker connection and at the base of spar at this location.

- o A deep cone extending below the ice line may be a good ice buoy candidate.

- o Spar buoys can be used for winter markers (Canadians currently use them).

- o Improvement is needed for ice buoys to provide a better daymark and yet present minimum exposure to ice.

- o Means of improving the quality of the chafe section of the mooring chain (where it is subject to greatest wear and abrasion by sand) should be investigated.

- o For plastic buoys, the use of ultra violet (UV) stabilized plastic may preclude fading of color and provide a brighter appearance.

- o An interchangeable radar reflector could be utilized. It would then be possible to use the radar reflectors for 8 ft. buoys on First Class Can or Nun buoys and those for 6 ft. buoys on Second Class Can or Nun buoys. Bases would be used interchangeably and the radar reflectors would fit all buoys.

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[1]See Project Summary No. 3 and Bibliographic References Nos. 148 and 151 for detailed discussions of ionomer from buoy applications and tests.

- o The use of commercially available radar reflectors may be considered to improve radar reflection.

- o Greater buoy stability (in roll) allows a smaller lens to be used on a light.

- o We need to concentrate on aids that can be self sufficient and require little if any maintenance. This involves use of new materials such as aluminum, composites and other non-corrosive, durable materials.

- o An eye-bolt or a recessed bar can be installed on the counterweight for the purpose of facilitating the handling operations. It can be welded on to the tube that goes through the counterweight and it can be incorporated into the design.

- o Counterweights may be fabricated in pieces and joined together to improve constructability.

- o In order to reduce wear and prevent dropping off of the buoy tube and counterweight, gussets can be welded to stiffen the tubes.

- o The use of gimballed lights for maintaining the optical lens level should be considered.

- o Filaments and light bulbs are the weak links in the buoy system. That is why every time the buoys are visited, the bulbs are replaced even if they appear to be still good. The introduction of automatic lamp changers has greatly eased this problem.

- o As a long term goal, converting floating aids to fixed aids should be investigated.[1]

- o There are about 1,000[2] of the 8 x 26 buoys in the USCG ATON System -- these buoys essentially drive the whole system. A serious investigation into making any improvements to assure that their replacements are smaller, lighter, and easier to repair may produce highly desirable results.

- o A need exists for a sound signal buoy for use in shallow waters. Currently 7 x 17 buoys are used for this purpose but they do not work well because of the swing-arm mooring. The 9 x 20 GR buoy was developed specifically for this purpose but it does not have a light. On the other hand, the USCG has a stockpile of 8 x 20 buoys of 1930's/1940's vintage which are not being made any more. It is possible to adapt an 8 x 20 or similar buoy for use as a lighted sound signal.

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[1]The USCG has investigated this subject. See Project Summary No. 24 and Bibliographic Reference No. 9.

[2]As stated by USCG District 9 during interview. The actural number of 8 x 26 buoys in the USCG system as of FY85 distribution is, according to Bibliographic Reference No. 32, closer to 1,800.

A.4 Applicable New or Advanced Technology

- Inflatable buoys could be designed for use in quick marking of danger areas.
- Rubberized coatings may be used on buoys for protection against fouling. The coating would have to be color impregnated.[1]
- Advancements in solar power technology should be incorporated into buoy designs.
- PVC (polyvinyl chloride), FRP (fiber-reinforced plastic) or GRP (glass reinforced plastic) materials should be considered for buoy hull construction. PVC buoys are currently being used in the North Sea.
- Feasibility of designing and constructing buoys with advanced hull types, such as SWATH or catamaran, should be studied.
- Consideration should be given to designing entirely new buoy systems for certain applications.
- In order to improve discernability at night, new types of signals such as gating or gating sequences of lighted channel buoys can be applied. It is understood that the USCG had experimented with this idea in 1974 ("Uniflash" systems).
- Investigate new technologies in the area of mooring systems for all buoy systems. The Coast Guard Spends nearly $2 million on chain mooring systems per year. This could be greatly reduced through use of new technologies in mooring systems. Also, look at the use of other materials to get increased performance and less maintenance on deployed aids to navigation.
- CALM and SALM articulated buoy/mooring systems currently used in non-ATON applications may serve to better identify buoy locations.
- For future applications, electronic position keeping systems may serve as an alternative to buoys for certain applications.

A.5 Impact of IALA

- Even the users of aids to navigation do not find the IALA topmark requirements necessary. U.S. pilots who board the foreign ships when they are in U.S. waters know what the buoys stand for; topmarks don't add anything.
- Topmark requirements will make some buoys hard to handle. An example is the danger buoys with two spherical topmarks.
- The danger topmark with two spheres becomes a fairway marker with the

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[1]See Project Summary No. 26. These coatings were tested and evaluated by the USCG and results were found unsatisfactory.

loss of one sphere. This is dangerous.

- The USCG has adopted IALA's Region B lateral marking system. Compliance is nearly 100%; however, the isolated danger mark ("x" visible from all directions) has not yet been developed.

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APPENDIX B
Buoy Technology Bibliography

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191. National Data Buoy Center. Users Guide and Operations Manual for Static Stability Program. Bay St. Louis,MS: National Data Buoy Center, March 1988.

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199. Speckter, H. E.; Haberkamp, H. "Studies of the Motion Characteristics of Large Navigational Buoys and Moored Hulls." Proceedings of the 10th IALA Conference (Paper 1.2.8) Tokyo: International Association of Lighthouse Authorities, 1980.

200. Static and Dynamic Analysis of a Moored Buoy System." U.S. Dept. of Commerce Report No. NDBCM 6113.1, Bay St. Louis, MS: April 1972.

201. Tucker, M. J. "Heave Response of a Spar Buoy." Ocean Engineering Vol. 9 No. 3 (1982).

202. Walden, R. G.; DeBok, D. H.; Gregory, J. B.; et al. Mooring Dynamics Experiment - A Major Study of the Dynamics of Buoys in the Deep Ocean. National Data Buoy Center Report NTIS Access No. 7805742, Bay St. Louis, MS.

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Appendix C
Buoy Technology Abstracts

General

4. Abbott, Geoff. "Small Solar Buoy (SSB) Design." Aids to Navigation Bulletin, Vol. 15 No. 2 (Dec/Jan 1986): 28-30.
This article outlines the design objectives and features of a small, solar-powered buoy proposed for the Coast Guard. The author describes the technology used in its development as state-of-the-art.

6. Berteaux, H. O. Buoy Engineering. New York: John Wiley and Sons, 1976.
This book is a general text on buoy engineering. Part I covers the mechanics of floating bodies including floatation, trim, dynamics of free-floating bodies, and hydrodynamic forces on constrained floating bodies. Part II covers the mechanics of mooring lines including statics of single-point and multi-leg systems and the dynamics of mooring lines. Part III covers oceanographic buoy systems including class descriptions, buoy system design, environmental problems, and deployment and retrieval techniques.

7. Bitting, K. R. Ice Buoy Demonstration Program. U.S. Coast Guard Research and Development Center Report No. CG-D-91-76, Groton CT: 1976.
The objectives of the ice buoy demonstration project were to test and evaluate modified standard buoys for winter use in the Great Lakes. The four standard buoys used in the tests were: 5x18, 9x20, 9x32, and 9x38. A prototype 16 ft. diameter octagonal buoy was also tested. The buoys were deployed at key locations in the Great Lakes during the winters of FY73, FY74, and FY75. The buoys were photographed by Coast Guard craft and mooring line tensions were measured.
The success of a buoy was found to be a function of both shape and ice conditions at the deployment locations. The 9x38 and 9x32 buoys were overrun by ice 8 to 10 inches thick, the 9x20 by ice 6 inches thick, and the 5x18 by ice 4 to 6 inches thick. The 16 foot prototype was found to list considerably due to ice on deck. Lantern damage was frequent on the buoys which submerged and it was also found that high holding-power anchors must be used for reliable mooring.

8. Blaney, H. "IALA Conversions." Aids to Navigation Bulletin Vol. 15 No. 5 (Jun/Jul 1986): 10-13.
This article clarifies some modifications to the U.S. aid to navigation system in order to conform with IALA standards.

9. Booz-Allen Applied Research, Inc. "Evaluation of Minor Marine Structures vs. Buoys." Unpublished Report for U.S. Coast Guard Headquarters, Contract No. DOT-CG-90506-A, Washington, DC: 1970.

The purpose of this report is to evaluate the technical and operational considerations which affect the use of buoys and marine structures as aids to navigation. The study also includes a life-cycle cost analysis of both marine structures and buoys.

The primary conclusions reached in this study are: structures are more effective aids to the mariner than buoys; the application of structures is limited by environmental, water depth, and bottom conditions; maintenance is less for structures and allows for smaller servicing vessels; the primary cost for both buoys and structures is the servicing vessel; life-cycle costs for buoys and structures are comparable when the servicing vessels are comparable; cost savings can be realized by improving servicing schedules and using smaller servicing vessels. The report recommends the structures be used where conditions are favorable and service schedules be improved.

10. Booz-Allen Applied Research. "Servicing System for Short-Range Aids to Navigation." Unpublished report for U.S. Coast Guard Headquarters, Contract No. DOT-CG-90506-A, Washington, DC: 1970.

The purpose of this report is to examine servicing systems for aids to navigation. The study examines facilities ashore and afloat and suggests possible changes in construction material and buoy-structure mix.

The report recommends the following: (1) the development of a family of lightweight plastic aids to navigation; (2) the use of minor marine structures instead of buoys where possible; (3) a reduction in servicing frequency for AtoNs; (4) the establishment of an effective buoy tracking program and a maintainability analysis for AtoNs; (5) modernization of existing and construction of new buoy tenders; (6) the establishment of Aid to Navigation Teams (ANTs); (7) the utilization of present shore facilities; and (8) the establishment of dual responsibility for aid service with ANTs providing routine and emergency service and large tenders used only when their more extensive capabilities are warranted.

11. Boy, R. L. "AtoN Engineering Developments." Aids to Navigation Bulletin Vol 18 No. 1 (1989): 15-16.

This article presents an overview of problems with and expected modifications to aid to navigation buoys. Changes to specific buoy hulls and on-board equipment modifications are discussed.

12. Boy, R. L. "AtoN Engineering Developments." Aids to Navigation Bulletin Vol. 17 No. 2 (1988): 24-26.
This article presents an overview of new developments in aids to navigation including modifications to correct problems with specific buoys. A list of upcoming projects is also provided.

13. Brandes, R. W. "Development of AtoN Programs for the Freely Associated States of Micronesia." Aids to Navigation Bulletin Vol. 17 No. 1 (Jan/Feb 1988): 14-18.
This article presents an overview of the aid to navigation system of Micronesia with reference to the use and capabilities of articulated beacons.

14. Cleveland, Harley and Glahe, Paul. "Experience of the United States Coast Guard with Large Navigational Buoys (LNBs)." IALA Bulletin 1983/4.
The article begins by giving the reasons for designing and building LNBs and explains that 12 have been built for the US Coast Guard, 8 of which are on station. The article then gives a full technical description of the LNBs, including their lights, sound signal systems, etc. It continues by giving information on the remote control and monitoring system, the weather sensing system, and the position monitoring and mooring systems. The article then presents information about maintenance, the electrical power system, etc. The conclusion gives details of the 3 collisions in which LNBs have been involved, and of a conventional buoy under development that may replace some LNBs.

15. Cleveland, Harley, and Glahe, Paul. "Everything You Wanted to Know about USCG Experience With Large Navigational Buoys." The Coast Guard Engineer's Digest, COMDTPUB P5240.2, Vol 22 No. 218 (Spring 1983).
This article is a reprint of a paper presented for the IALA entitled "Experience of the United States Coast Guard with Large Navigational Buoys (LNBs)". The abstract is listed under abstract no. 14.

16. Code of Federal Regulations, Title 33. Office of the Federal Register, National Archives and Records Administration, Washington D.C.: 1985.
This publication is a listing of federal regulations regarding U.S. Coast Guard aids to navigation and private aids.

17. DeBok, D. H. and Walker, R. T. Analysis of "Offstation" Buoys. U.S. Coast Guard Research and Development Center Report CG-D-67-79, Groton CT: May 1979.
A review of 51 months of Coast Guard records for buoys exhibiting inadequate anchor reliability is described along

with results and recommendations. Two types of low reliability are considered: (1) buoy stations with lower than average anchor reliability (repeat offenders) and (2) stations for which average reliability is inadequate (critical buoys). Initially, average failure rate is determined using a failure rate diagram. This rate is applied to identify buoy stations with below average anchor reliability. A listing of these buoys is provided. Classification of buoy station characteristics and causes of failure are provided for reported anchor failures. Estimation of the number of "critical" buoy stations is included along with classification of characteristics and evaluation of failure rate.

19. Drijfhout van Hoff, J. F. Aids to Marine Navigation - Volume I. Maritime Research Institute of the Netherlands Rept R-238, Netherlands: 1982.
This publication is a general instructional text for the study of maritime aids to navigation. Subjects discussed in Volume I are: fundamental processes in marine signalling, lighted visual aids, unlighted visual aids, acoustical aids, conventional radio aids, hyperbolic radionavigation systems, microwave aids, and hardware.

20. Drijfhout van Hoff, J. F. Aids to Marine Navigation - Volume II. Maritime Research Institute Neth Rept. R-238, Netherlands: 1982.
This publication is an instructional text for the study of maritime aids to navigation. Subjects discussed in Volume II are: aids for oceanic navigation, aids to coastal navigation, aids for navigation in confined waters, and hydrography and aids to navigation.

22. Foley, W. E. "The ACCORDION Buoy." Transactions of the 1964 Buoy Technology Symposium. Washington D.C.: Marine Technology Society, March 1963.
This paper describes the Project ACCORDION buoy. Project ACCORDION was a joint Coast Guard and Federal Aviation Agency program to provide Trans-Atlantic aircraft with improved navigational data. The program required a navigational buoy consisting of a daymark, light, and radar reflector capable of being moored in 2000 fathoms. Discussed here are the first and second buoys and how the design for the second buoy evolved from the first. Also discussed are the buoy payload signal systems, moorings, and problems in setting the buoy.

23. Fontneau, P. B. Lightweight Buoy System Tests Phase I - Testing and Development Center Tests. U.S. Coast Guard Interim Report No. USCG-518, 1970.
The feasibility of using a small high speed servicing craft for handling an unlighted lightweight buoy and its

mooring is demonstrated in this interim report. Modifications to the small boat to be used for buoy servicing, speed, horsepower and propeller selection trials, buoy handling experience and methods, and development of buoy handling equipment are described. The existing 120 hp TICWAN with a 16x13 in. propeller is used for buoy handling. A technique for setting and retrieving buoys is described. Problems encountered with equipment prompted several suggestions for minor changes. However, use of the TICWAN in its present configuration is recommended for Phase II deployment of additional first generation buoys in the Alabama River.

24. Frazier, Ronald H. and Millbach, Miles A. "AtoN Research and Development." Aids to Navigation Bulletin Vol 18 No. 3 (May/Jun 1989): 17-18.
This article is a collection of short updates on USCG R&D efforts in regard to aids to navigation. The article focuses mainly on buoy payload.

25. General Dynamics Electronics Division. Report of Technical and Cost Data on the Large Ocean Buoys. Report No. AD-A955 130: General Dynamics Corporation.
The large discus ocean buoys are deployed in many oceans of the world serving as Ocean Data Acquisition Stations, lightship replacement, and as other aids-to-navigation. Effective and economical, they have added a new dimension to solving problems in the marine environment. For 14 years, General Dynamics has been actively engaged in the development of ocean buoy systems. During this period, acheivements have included the invention of the thick discus hull, use of computer designed mooring systems, design of power systems, design of modular sensor systems, development of computer controlled and hard wired data acquisition and control systems, and HF communication systems. The technical descriptions contained in this report have been selected from the family of hulls and subsystems available to present the most appropriate buoy for the anticipated NFEC mission requirements.

26. Glahe, P. J. "Recent Developments in a Navigational Buoy For Use in Ice Conditions." Oceans '80 Conference Record: Institute of Electrical and Electronics Engineers, 1980.
This paper traces the conception, design, construction, and testing of a steel navigational buoy developed for use in the ice conditions normally encountered in coastal bays. The design centers around preventing the accumulation of spray formed ice on the buoy superstructure and introduces significant changes in the light/lens configuration to insure survivability should the buoy be dragged under during ice flows. Two prototype buoys, 6 feet in diameter and 16 feet in overall length, were manufactured. These buoys were

tested in the Chesapeake Bay and later in the Straits of Makinac during the winter of 1979/1980. The evaluation showed promise and construction of 40 more buoys was begun in March 1980.

28. Glahe, P. J.; Armstrong, M. C. "General Report Topic 3 - Floating Aids to Navigation." Proceedings of the 11th IALA Conference, Brighton, U.K.: International Association of Lighthouse Authorities, 1985.
This article is an overview of several reports presented at the 11th IALA conference pertaining to buoys and floating aids to navigation with summaries of findings on the following subjects: large navigational buoys, ice buoys, articulated lights, special offshore buoys, plastic buoys, and moorings.

29. Greenberg, L., et al. SRA Resource Management Final Report on Task 1: Measures of Effectiveness. Mandex, Inc. Report to U.S. Coast Guard No. CG-D-20-86, Washington, DC: 1986.
This document describes the first phase of a five-year study designed to develop a decision model capable of supporting the resource management activities of the Coast Guard's SRA program. The first phase, which included visits to virtually all Coast Guard Districts and meetings with pilots associations and selected user groups resulted in the development of standardized measures by which the predicted outcome of proposed management decisions can be expressed. The spectrum of decisions includes: acquisition and deployment mix, maintenance, staffing and training of personnel, as well as decisions to invest in R&D and technological innovation. Measures of effectiveness developed under the first task deal primarily with safety and timeliness. A framework is established for expressing the components of these dimensions in a fashion suitable to the situation at hand. Other measures of effectiveness dealing with less tangible issues are also defined.

30. Heinz, Kurt J. "Exposed Location Buoys." Aids to Navigation Bulletin Vol. 14 No. 5 (Jun/Jul 1985): 15-16.
This article describes design features, capabilities, and locations of 9x35LR exposed location buoys slated for deployment in late summer 1985.

31. Heinz, Kurt J. "Lighted Whistle Buoy Design Evolution." Aids to Navigation Bulletin Vol. 15 No. 4 (Apr/May 1986): 15-17.
This article reviews some design features and changes to lighted whistle buoy design since 1952.

32. Henderson, Dan. "New Buoy Systems - Project Definition." Unpublished U.S. Coast Guard Internal Report Project No. 2710, 1987.

This report outlines a proposed New Buoy Systems project to be initiated in FY89. The project is intended to accomplish three goals: 1) develop a lighter weight, long life replacement buoy system for the 8 and 9 foot buoys, relying heavily on articulated structure technology; 2) develop a lightweight, long life, unlighted sound buoy; and 3) develop new Western River buoys that will be more cost-effective than those currently in use.

35. Humphery, J. D. Operational Experiences with Waverider Buoys and Their Moorings. Institute of Oceanographic Sciences Report 145, Wormley, U.K.: 1982.

The first IOS Waverider buoy was deployed at the Eddystone site on 25 June, 1973. Since then a total of 10241 buoy-days on site have been logged up to 31 December, 1981. This approximates to 28 buoy-years on site, and during this time, considerable experience has been gained on the performance of the buoys and their moorings. This report sets out to list some of the latest improvements in mooring design.

36. International Association of Lighthouse Authorities. "Development of Aids to Navigation in the Year 1988." IALA Bulletin 1989/3 (Supplement).

This bulletin gives country-by-country briefs on research and development efforts with regard to aids to navigation.

37. International Association of Lighthouse Authorities. IALA Maritime Buoyage System Guidelines. Paris: International Association of Lighthouse Authorities, 1983.

This publication presents the official guidelines and rules for the IALA Maritime Buoyage System.

38. Kulbrodt and Elschner. "Experience Acquired With Inland Waterways Buoys." Proceedings of the 11th IALA Conference (Paper 3.1.0) Brighton: International Association of Lighthouse Authorities, 1985.

In the mid-fifties the Federal Waterways and Shipping Authority of the FRG was required to set more and more buoys on inland waterways. Following the development of some buoy prototypes, testing was accomplished in the towing basin of a shipbuilding research establishment. These tests resulted in a standard buoy shell which is feasible for all inland waterways. This standard buoy shell has an outside diameter of 1050 mm and a total weight of 250 - 480 N, depending on the shell material and foam packing. Now that these buoys have been in operation more than one decade,it is possible to report on experience acquired in many respects. The buoy

shell and topmarks have been made of different materials including metals and plastics. The buoy can be fitted with different ballast weights and has several mooring attachment points. Experience with respect to strength, corrosion, floatation, trim, mooring, handling, maintainability, and cost are discussed in this paper.

39. Lighted Whistle Buoy Design." Aids to Navigation Bulletin Vol. 16 No. 1 (Oct/Dec 1986): 8-10.
This article suggests several design characteristics for lighted whistle buoys. Most of the suggestions are aimed at improving handling and maintenance of the aids.

40. Lucas, Robert S. "Naval Engineering Overview." The Coast Guard Engineer's Digest, COMDTPUB P5240.2, Vol. 22 No. 218 (Spring 1983).
This article is a brief summary of USCG research and development efforts regarding aids to navigation. Areas discussed include solar powering of aids to navigation, articulated beacons, and exposed location buoys. It is good summary material but not many specifics are presented.

41. May, D. R. New Technologies and Developments in NDBC Buoy and Mooring Design. National Data Buoy Center, Bay St. Louis, MS: 1988.
Since the early 1970's, the National Data Buoy Center (NDBC) has deployed deep-ocean weather buoys and mooring systems. Starting in 1980, new deep-ocean, bottom-insensitive, inverse-catenary mooring systems were deployed based on developments of the late 1970's. Since 1980, refinements to the basic mooring design have been made incorporating recent technical developments, such as use of noncorrosive plastic materials. In addition, new developmants have been made in mooring design for reduced mooring costs, in recoverable mooring systems, and in prevention of damage to mooring lines due to fishbite. During this same period, buoy hulls have undergone new developments, with the trend being toward smaller, lightweight, more durable hulls. Use and development of new foam buoys has recently been undertaken for application in nearshore coastal areas.

43. Naus, David A. "Have We Missed the Mark?" Aids to Navigation Bulletin Vol. 15 No. 5 (Jun/Jul 1986): 7-9.
The author describes the cardinal mark system and advocates its use in U.S. waters.

44. NDBO Buoy Deployment and Retrieval Operations. NOAA Data Buoy Office Report NDBO F-470-1, Bay St. Louis, MS: National Data Buoy Center, 1979.
This report contains visual aids for a NDBO presentation on data buoy deployment and retrieval

operations. No narrative is provided, but several photographs are included which show typical operations.

46. Papp, R. J. "AtoN Engineering Developments." Aids to Navigation Bulletin Vol. 18 No. 3 (May/Jun 1989): 16.
This article presents comments on R. L. Boy's article of the same name in the Jan/Feb issue. The author relates field experience in many areas and makes suggestions for improvement of maintenance, life, and handling of aids to navigation.

48. Pierson, C. B. "High-Precision Radio-Positioning Offshore Navigation Buoy." Sea Technology Vol. 23, No 3 (1982).
In 1980, high precision radionavigation signals in the Hibernia prospect area of Newfoundland, Canada, were available for offshore geophysical exploration 8 hours out of 24. This year they were available 24 hours-a-day. The application of elasticallly tethered buoy technology was responsible for this threefold increase in navigation signal availability more than 300 KM out to sea. In the fall of 1980, Geophysical Service, Inc. (GSI), Dallas, TX contracted NAICO, Bedford, NH, to develop a high accuracy offshore navigation system utilizing elastically-tethered buoy technology. (NAICO recently changed its name the Buoy Tec.) Such a buoy system would allow radionavigation systems to be placed in the local prospect area rather than constrained to shore-based locations.

54. Spherical Buoy." Aids to Navigation Bulletin Vol. 14 No. 2 (Dec/Jan 1985): 19.
This article presents technical specifications on a new spherical buoy for unlighted midchannel marking introduced to conform with IALA conventions.

55. Sunken Buoy Recovery Weight." Aids to Navigation Bulletin Vol. 17 No. 2 (Mar/Apr 1988): 7-8.
This article is a listing of flooded and non-flooded buoy weights for aids to navigation buoys currently in service.

56. Timpe, G. and Rainnie, W. O. "Development of a Value-Engineered NOMAD Buoy." Oceans '82 Conference Record, Washington D.C.: Institute of Electrical and Electronics Engineers, 1982.
Since the mid-1970's, the National Oceanic and Atmospheric Administration (NOAA) Data Buoy Office (NDBO) has used Navy Oceanographic Meteorological Automatic Device (NOMAD) Buoys as a part of their ocean data gathering network. These U.S. Navy-built, 20 ft. long, boat-shaped hulls have proven to be extremely seaworthy buoys. The hulls are reliable, easily transportable, and for many applications they are an attractive alternative to the

conventional 40 ft. and 33 ft diameter discus-shaped buoys. As a result, NDBO, in early 1979, began actively pursuing the idea of designing and constructing a second generation, value-engineered version of the NOMAD buoy. A consulting firm was contracted to redesign the NOMAD hull, and in June 1981, construction was started on a series of five new NOMAD buoys. This paper describes the design and construiction of the NOMAD buoy, and details the efforts of industry and government to produce a reliable, cost effective data buoy.

57. Timpe, G. L. "Use of NOMAD Hulls as Severe Environment Buoys." Proceedings of the 1983 Symposium on Buoy Technology, New Orleans, LA: Marine Technology Society, April 1983.

In the past, the NOAA Data Buoy Center (NDBC) had used 12-m and 10-m discus-shaped buoys on their severe environment stations in the North Atlantic and Pacific Oceans, and had restricted the 6-m boat-shaped Navy Oceanographic Meteorological Automatic Device (NOMAD) buoys to less severe locations. However, the phenomenon of the large discus buoys capsizing in steep breaking waves has led to a re-evaluation of this practice. In 1979, a NOMAD buoy was moored next to a 12-m discus buoy on a North Pacific station in an effort to test both the survival of the hull and the quality of its transmitted data. The sucess of this experiment, coupled with NDBC's continued good experience with the hull and the economic advantages of using a smaller buoy, has led to the recent recertification of the NOMAD buoy for severe environments. This paper covers the NOMAD buoy's background, details and results of the North Pacific tests, and the basis for its recertification.

58. Tousley, Brian. "Aids to Navigation for Safe Harbor Detection." The Coast Guard Engineer's Digest, COMDTPUB P5240.2 (Summer, 1985).

This article deals with improving the visibility of aid to navigation towers. The article also focuses on design detail and cost considerations. This article deals mainly with fixed towers but some considerations may apply to floating aids as well.

59. Tozzi, John T. Swift-Running Rivers Work Group Formal Reports Pertaining to Investigations and Analyses Performed Between June 1974 and August 1975. U.S. Coast Guard Office of Research and Development Report No. CG-D-58-76, Groton, CT: May 1976.

This report contains the two formal reports which were generated by the Swift-Running Rivers Work Group during its tenure, between June 1974 and August 1975. The Group was formed in response to a mandate from the Chief of Staff of the U.S. Coast Guard to investigate what appeared to be significant aids to navigation problems in the Western

Rivers System of the United States and to recommend a long-term R&D approach to their solution. The recommendations of the Work Group are stated explicitly in the first few pages of the final report of November 1975. Supporting information in the final report and the Work Group's Status Report of October 1974 are included under this cover for completeness and clarity.

61. United States Coast Guard. ACCORDION Buoy on Ocean Station CHARLIE. 3rd District Report, August 1963. (Available through the Defense Technical Information Center.)
The purpose of the report is to document the ACCORDION buoy equipment, how it was transported to station, set on station, its operational capabilities, and recommendations for improvement.

62. United States Coast Guard. Aids to Navigation - Technical COMDTINST M16500.3. Washington, D.C.: 1979.
This publication is the U.S. Coast Guard's instruction manual governing selection, installation, and maintenance of equipment for the Short Range Aids to Navigation Program. Included in this manual are technical data on the Coast Guard Buoys officially in operation.

63. United States Coast Guard. Aids to Navigation Manual COMD2INST M16500.3A (2nd District). St. Louis, MO: 1989.
This manual provides guidelines for procedures and policies regarding the aids to navigation system in the Coast Guard Second District. This district is primarily responsible for buoys and other aids on the U.S. Western Rivers system.

64. United States Coast Guard. Ocean Engineering Report 17E: Initial Cost of Buoys. U.S Coast Guard Report No. CG-250-17E, Washington, DC: 1971.
This report is intended to furnish specific information for: 1) Estimating the costs of a complete buoy establishment; 2) Showing which major components must be assembled in order to make up a new buoy; 3) Indicating where these major components may be procured. Cost data is provided for all Coast Guard buoy classes in service in 1971.

65. United States Coast Guard. Short Range Aids to Navigation Study - 1983. U.S. Coast Guard Report, Washington, DC: 1983.
This report is the result of an intensive analysis of the SRA system by the Coast Guard. The study is broken into five parts: 1) General Issues, 2) Offshore, 3) Coastal and Inland, 3) Great Lakes, and 4) Rivers. Within each section, the report addresses servicing requirements, tender utilization and cost, system planning factors, long term system alternatives, cost analysis of operational

alternatives, and a summary of recommendations. Most of the conclusions reached by this study relate to servicing systems and buoy tender operations, although there is some general discussion of past buoy research and development.

67. Vreeswijk, J. K. "Efficiency in Buoyage Maintenance." IALA Bulletin 1977/4.

A thorough study was made in 1974 in the Netherlands to rationalize buoyage maintenance by withdrawing maintenance from crews' duties and creating facilities for indoor work.

Two lighthouse tenders (out of 17) have already been decommissioned and another one will follow in 1978.

Local workshops are being closed or transformed into storage yards and 4 new central workshops are being established and equipped with water jet, forced ventilation, and airless spray-painting facilities.

Special attention has been paid to the fast transport of the buoys from the tender to the workshop and inside the workshops and vice-versa.

70. Wood, V. "Collecting Data in the Ice Age." Sea Technology, Vol. 26 No.2 (1985).

The RIOT (Real-time, Ice-resistant Oceanographic Telemetry) buoy is capable of collecting current and tide data in real-time and relaying this information to a receiving station up to 15 kilometers away. This spar buoy is eleven meters long and approximately a third of a meter in diameter. It is constructed of heavy, machine-wound fiberglass pipe and is capable of withstanding the impact of a vessel or an ice mass. In the four Beaufort drill seasons during which RIOT has evolved, a buoy hull has never been damaged by ice or vessel impact. The spar buoy design allows the system to be overrun by ice; dragged along the bottom of an ice mass, it will resurface when the ice has passed. The "brain" of the system is the remote telemetry unit (RTU).

73. Arnquist, J. A. "Field Testing of the 2CPR Foam Buoy with Light and Solar Panel." Unpublished U.S. Coast Guard Research and Development Center Interim Report, Groton, CT: Sept. 1986.

This report outlines tests performed at the Coast Guard R&D Center on a standard 2CPR foam buoy, fitted with a solar array and lantern for operation as a lighted aid to navigation. The buoy was deployed along with a 5x11 LR buoy,also modified to accept a solar panel, and a discrepancy buoy in order to obtain a comparative evaluation.

The foam buoy modification to a lighted, solar powered buoy was a success. The 2CPR performed as well a the 5X11 LR in terms of light visibility in seas up to 5 ft. and winds up to 37 mph and consistently performed better than the discrepancy buoy. Overall, the feasibility of a solarized foam light buoy was confirmed, and recommendations for future development are outlined.

74. Articulated Lights." Aids to Navigation Bulletin Vol. 15 No. 3 (Feb/Mar 1986): 36-37.

This article presents some comments on problems experienced with a Great Lakes articulated light during evaluation in ice.

75. Baldwin, K. C.; Swift, M. R.; Mielke, D. J. "Quarter Scale Collision Tolerant Pile Concepts: Peripheral and Central Stay." Oceans '87 Conference Record: Institute of Electrical and Electronics Engineers, 1987.

Two 1/4 scale (approx. 12 ft tall) Collision Tolerant Pile Structure (CTPS) designs were developed for the deployment of navigational aids in shallow water. The CTPS concept consists of the marker/light mounted on a single pile hinged just above the mud line. The two systems considered here are a peripheral stay, central universal joint hinge concept, and a central stay concept.

Testing included hinge restoring moment-angle tests, barge collision experiments, and in-situ measurement of the response to wave motion. Field experiments demonstrate that the pile sustains negligible damage during barge collisions, recovery is prompt, and pile motion in large waves is very small. Experimental results were compared with a 2-dimensional computer simulation of the pile dynamics with good agreement.

76. Bennett, Derek J. "Moored Buoy for Precise Navigation in Coastal Waters." 7th Annual Offshore Technology Conference Proceedings, Houston, TX: Institute of Electrical and Electronics Engineers, May 1975.

A light-weight buoy system has been developed for the Navy for precise navigation in coastal waters. The mooring

employs a unique method, whereby a low drag wave rider buoy is tethered by a thin cable that is coupled to a spring-powered wave-and-tide compensator reel located in the anchor. Moored in this manner, the buoy is resistive to position changes caused by waves and currents. The buoy provides the waterborne platform for mounting navigation systems.

A description is presented of the mooring system, the method of automatically establishing the mooring and the hydrodynamic performance of the buoy. The results of sea tests are also summarized.

77. Brazilian Lighthouse Authority. "Note on the Use of Resilient Beacons." IALA Bulletin No. 78 (1972/2).

In this paper, the Brazilian Lighthouse Authority reports on the use of resilient beacons in various channels which was more or less satisfactory. Its conclusion is that such beacons should not be used in sites with a light sea bed.

78. Brooks, J. "New London Harbor Channel Articulated Light 1." Aids to Navigation Bulletin Vol 16 No. 6 (Oct/Dec 1987): 9-10.

This article evaluates an articulated light which was placed in the New London Harbor Channel. Its performance is compared to that of the 8x26 LR buoy it replaced. Service life proved to be much shorter than expected and the author recommends switching back to the 8x26 LR buoy.

79. Cavaleri, L. "Semi-rigid Connector for Buoys and Marine Platforms." Ocean Engineering, Vol. 7 No. 3 (1980): 447-456.

A system is described which has the capability of maintaining two large structures apart, floating or submerged, but allowing their relative movements due to current, waves, and wind. Such a system has been designed and built. The tests carried out show that the developed theory is correct within the specified limits of validity. A practical test in the sea has shown the efficiency of the system and suggested some possible improvements. Its main characteristics are simplicity, reliability, and low cost.

80. Cloutier, R., et al. Design, Development, and Testing of a Quarter Scale Collision Tolerant Pile Structure. Unpublished report for UNH course Tech 697, Univ. of New Hampshire: 1985.

The Collision Tolerant Pile Structure (CTPS) student project was an extension of a Coast Guard sponsored project conducted at the University of New Hampshire. The Coast Guard sponsored project investigated the problem of damage to rigid pile navigation markers from collisions with towed barges. Basic research, including preliminary design concepts, computer simulations, and small scale models was

conducted during the summer of 1984 to develop a compliant pile navigation marker.

In this project, the preliminary research and design was used as a basis for the design, development, and testing of a quarter scale CTPS. This work included a computer analysis, working drawings, fabrication, and installation of the CTPS at a location in the Great Bay Estuary. The CTPS was taken out of the laboratory and into the field under actual conditions where actual collision testing was performed.

81. Colburn, W. E. "Fast Water Buoy Development." Aids to Navigation Bulletin (Jun 1974-Jul 1975): 13.

This article presents a short summary of plastic hemispherical buoy development for fast water service.

82. Colburn, W. E. and Ryan, D. D. Lightweight Low Drag Fast Water Buoys. U.S. Coast Guard Research and Development Center Report CG-D-5-77, Groton, CT: Dec 1976.

This report presents the development of the Coast Guard fast water buoys. The development of a lightweight buoy which can be used in currents up to 8 MPH was the design goal of this study. Buoys presently in use tend to submerge in fast water and collect debris. After design, testing and evaluation of several types of buoys, two sizes of spherical section buoys have been developed. The larger buoy was designed for 3 to 8 MPH currents, is 5 feet in diameter, weighs 160 lbs, and has a nominal daymark range of 1-1/4 mile. The smaller buoy was designed for 0 to 6 MPH currents, is 4-1/3 feet in diameter, weighs 150 lbs, and has a nominal daymark range of 1 mile. Both buoys have shells made of high-density polyethylene plastic and are foam-filled.

This report discusses the project history, hull section, hull configuration and material selection for the prototype buoys, the persistent problem of debris collection, and specification for the buoys being procured.

83. Colburn, W. E. and Thompson, W. R. Lightweight Lighted Buoy Development for Use as Discrepancy Navaids. U.S. Coast Guard Research and Development Center Report CG-D-2-77, Groton CT: Dec. 1977.

This report presents the development of the Coast Guard discrepancy buoys. A discrepancy buoy is used as a temporary floating aid while the normal aid is not available. These buoys are also used for special aids such as the temporary marking of wrecks.

The 190 lb prototype buoy has survived storms with up to 68 MPH winds and waves in excess of 5 feet. The buoy provides 1 NM daymark range from its interchangeable CAN and NUN shapes, a 1 NM radar reflectivity, 3 NM light range, and 40 days of unattended operation with standard batteries. Solar panels may be used for extended deployment periods.

The buoy has been tested in currents of up to 5 KTS. The buoy was designed for ease of handling from a small boat and for minimal maintenance.

This report covers the project history, description of the prototype buoys, an evaluation of the operational requirements, suitable moorings, and conclusions.

84. Colburn, W. E.; Tozzi, J. T.; Glahe, P. J. "Lightweight Buoy for Fast Currents." Oceans '76 Conference Record, Washington D.C: Institute of Electrical and Electronics Engineers, 1976.

This paper is a detailed account of development, design, and testing of USCG fast-water buoy hulls. Several designs were tested including discus, barge, tear drop, and hemispherical hulls. The hemispherical hulls with offset mooring eyes were found to perform the best.

85. Cutler, J. W. Design of an Articulated Spar Buoy. U.S. Coast Guard Research and Development Center Report CG-D-71-81, Groton, CT: Feb 1980.

A generalized analytical model of the wind, current, and wave forces on an elliptical cylinder is presented with specific application to predicting the list angle of an articulated spar buoy. The major physical and environmental parameters present in the system are then analyzed to determine their relative influence on these forces and moments.

Data to validate this analytical model was obtained from both laboratory and field tests. Model tests in a circulating water channel showed that directional stability was a significant factor in the performance of elliptical cross-section spars. Of the shapes investigated, only a circular cylinder with a splitter plate was found to be stable. Both the model and field test measurements of list angle showed good agreement with the analytical model.

On the basis of these results, it was concluded that the analytical model is a good predictor for circular spars.

89. Glahe, P. J. "Unlighted Plastic Buoy for Use in Fast Currents." Proceedings of the 10th IALA Conference (Paper 3.1.14) Tokyo: International Association of Lighthouse Authorities, 1980.

The Western Rivers of the United States (Mississippi and its tributaries) have extremely fast currents. Associated with the fast current environment is a substantial amount of debris, ranging from mill grass to fallen trees. The buoys previously used tended to submerge in fast currents and generally could only be recognized by the surface water disturbance. After design, testing, and evaluation of several types of buoys, a lightweight buoy with a hemispherical hull section was adopted which can be used in currents up to 6 knots. Use of over 2200 of these

buoys has resulted in a significant improvement of buoy performance on the river.

90. Higley, P. D. "Limp Log Mooring Design." Oceans '81 Conference Record, Boston, MA: Institute of Electrical and Electronics Engineers, 1981.
The Limp Log buoy was developed to fill the need for a telemetry buoy capable of long term survival in the ocean. The buoy includes a reliable data link from the sea floor to the sea surface and a surface buoy capable of satisfying the constraints required by a satellite antenna. The Limp Log design combines the surface buoy with the surface tether in the form of a long, tapered, buoyant, flexible hose filled with syntactic foam. By coiling the data lines inside the hose, the strength member and the data line are mechanically isolated from each other and the stress in the data line becomes negligible. This construction eliminates the interface between the surface buoy and its mooring and provides a nearly indestructable buoy with no stress concentrations and no lumped masses to resonate. This buoy design is a new concept and can provide the long desired characteristics of simplicity and survivability an a severe environment.

91. Jaskulek, S.; Hoffman, E. J.; Allen, W. E. Feasibility Study for an Advanced Lighted Aid to Navigation. U.S. Coast Guard Research and Development Center Report CG-D-48-81, Groton, CT: Sept. 1981.
This report discusses a Coast Guard advanced aid to navigation network. Various light sources, positioning systems, and radio links are investigated for suitability to solar powered marine aids. A modular microprocessor-based aid, capable of self diagnostic monitoring and differential LORAN-C positioning is described. A communication system between the aids and shore stations, using conventional or meteor-burst VHF or a GOES satellite link, is examined, showing the first and last options to be most viable. Inter-aid flash synchronization schemes, and data transmission formats, polling methods, and system performance analysis are discussed. Having established the technical feasibility of the advanced aid concept, cost and reliability estimates are performed on the proposed systems. Finally, recommendations on areas requiring further study are presented.

93. MacNanmara, E. J. and Wilkins, A. H. "An Emergency Wreck Marking Buoy." Proceedings of the 11th IALA Conference (Paper 3.2.6), Brighton, U.K.: International Association of Lighthouse Authorities, 1985.
This report describes a buoy which is supplied in kit form, can be easily assembled, complete with a combination of navigation aids with a service period in excess of 4

weeks. Such a buoy can be permanently carried aboard a tender, taking up a minimum of stowage space and offers, at the time the wreck occurs, additional flexibility for movement of a tender and an adequate period to prepare a more permanent buoy.

94. McClure, Alan C. and Kirschner, Ivan N. "Semi-Submersible Buoy for Stormy Seas." Transactions of the 1983 Symposium on Buoy Technology, New Orleans, LA: Marine Technology Society, April 1983.
The semi-submersible buoy, consisting of an open lattice of tubular members, has been shown to possess excellent durability in severe sea conditions. For applications requiring a steady platform, such as data telemetry, the semi-submersible is particularly suitable.
The paper describes the inherent characteristics of this class of buoy and compares them with other widely used buoys. Designs for two buoys of different size and application are presented as examples of the semi-submersible buoy.

95. Miller, M. R. "Synthesis of a Collision Tolerant Fixed Navigation Marker System." Master's Thesis, Naval Postgraduate School, 1982.
The collision tolerant navigational marker system study was undertaken to determine the feasibility of using rubber as a flexure element when mounted in a fixed navigational structure for shallow water applications (20 ft. depth or less). Quantitative evaluations will be made of the system's technical feasibility, performance under environmental loadings, availability, associated installation systems, and cost. It is the intent of this work to develop a data base, investigate the use of mathematical/computer models, and develop a configuration matrix of installation modes.

96. Sataye, N. N. "Singapore's Resilient Beacons - An Ideal Aids to Navigation." Proceedings of the 10th IALA Conference Tokyo: International Association of Lighthouse Authorities, 1980.
The ultra rapid industrial expansion in Singapore from the mid 1960's onwards had a tremendous impact on growth of shipping activity in the port. This phenomenal growth in shipping called for additional aids to navigation. In order to minimize maintenance requirements of buoys and repairs to pile mounted rigid beacons the Hydrographic Department of the Port of Singapore Authority (PSA), borrowing on previously conceived design, developed an aid and named it the resilient beacon. This aid is easy to distinguish by day and night. It consists of an anchor weight, connected through a universal joint to a hollow tower which carries the floatation chamber and an aluminum top mark fitted with a day mark and a gimbal-mounted light.

The resilient beacon has proved to be extremely popular with mariners. It requires very little maintenance and incorporates all of the advantages but does not suffer from the disadvantages of the buoy and the pile mounted beacon.

97. Semi-Submersible Buoys Moored in Ultra-Deep Water." Ocean Industry Vol. 22 No. 9 (1987): p. 109.
Five semi-submersible buoys supporting antennas for a U.S. Air Force aircraft training range have been installed by Cubic Corp. Defense Systems Division in a deepwater area of the Pacific Ocean offshore Okinawa. Resembling miniature semi-submersible platforms, the buoys were designed by Alan C. McLure Associates Inc. of Houston and Built by Sumitomo Heavy Industries in Japan. Due to the low motion amplitude of the buoys, a small aperture antenna can be used, reducing power demand. This allows use of economical solar panels to generate electric power for lights and electronic systems. This same motionless characteristic alows electronic engineers to climb the masthead, 85 ft above the water surface, to make antenna connections or adjustments.

98. Smith, Dean "Articulated Lights." Aids to Navigation Bulletin Vol.14 No. 5 (Jun/Jul 1985): 17-18.
This article is a description of USCG plans for future articulated light deployment and a short synopsis of design features. Expected performance in ice is also discussed.

99. Smith, Dean. "Field Modification for Articulated Lights." Aids to Navigation Bulletin Vol. 15 No. 4 (Apr/May 1986): 6-7.
This article presents field modifications performed on articulated lights to reduce the number of structural failures experienced after their recent deployment. The modifications mostly center on the connection flanges of the extension pipe sub-assembly.

100. Strahl, D. "Articulated Lights." Aids to Navigation Bulletin Vol. 17 No. 2 (Mar/Apr 1988):
This article gives a short description of articulated lights followed by a synopsis of problems discovered in service. Solutions to these problems are proposed in the article.

102. Tsukinuki, Yoshito; Nagao, K.; Ojima, R.;Goda, Y.; Suzuki, Y. "Study of the Resilient Light Beacon." Proceedings of the 10th IALA Conference (Paper 2.2.1), Tokyo: International Association of Lighthouse Authorities, 1980.
Together with conducting tests with hydraulic models of the resilient light beacon in relation to waves and currents, tests were also conducted in seas of 5 meter depth with marine models. The values calculated from numerical analysis were compared with the results of tests conducted

with the marine and hydraulic models in relation to waves, and an effective numerical calculation program was developed that would estimate the movement of the resilient light beacon. The oscillation characteristics of the resilient beacon in currents were also clarified.

104. Walker, S. "Deploying An Articulated Beacon." Aids to Navigation Bulletin, Vol. 12, No. 2, March 1983.
No abstract available at this time,

106. Whitaker, C. T. "Port Hedland Sarus Tower." IALA Bulletin No. 64 1975/4.
The Sarus tower combines the reliability of a fixed beacon with the flexibility, low capital cost and ease of installation of a lighted buoy. It consists of a base, a tower divided into three main sections - the lower cylinder filled with water ballast, the buoyancy chamber, and the upper cylinder carrying a working platform, a battery compartment, and a ballast pipe - and the light structure. The approximate range of the light is 10.5 miles.
Stability particulars and heeling curves, tower installation particulars, and maintenance and servicing details are provided.

107. Abbott, Geoff. "Solar Designs for 5', 3', and Discrepancy Buoys." Aids to Navigation Bulletin, Vol. 15 No. 5 (Jun/Jul 1986): 14-15.

This article covers the conversion of 5x11 and 3-1/2x8 buoys to solar power with additional modifications to maintain stability with the new equipment installed.

108. Amy, J. R. "Development of Radar Reflectors for Buoys in the Coast Guard." The Coast Guard Engineer's Digest, COMDTPUB P5240.2 (Oct/Nov/Dec 1973):

This article traces the development of radar reflectors for USCG aids to navigation from 1948 to 1973. Included in the discussion is a list of factors which affect the range of radar reflectors and an evaluation of tests performed on new reflectors.

109. Bitting, K. R. "Rubber Band Mooring." Aids to Navigation Bulletin (July 1975): 12.

This article presents a brief update on research and development efforts to develop elastic moorings. The goal of the study was to reduce buoy watch circles. Some results of tests performed in shallow water are discussed.

110. Bocconcelli, A. "Engineering Surface Oceanographic Mooring (EOSM)." Oceans '89 Conference Record: Institute of Electrical and Electronics Engineers, 1989.

An Engineering Surface Oceanographic Mooring (EOSM) Program has been initiated by the the Woods Hole Oceanographic Institution to permit the long-term evaluation of prototype mooring components such as steel and Kevlar armored electro-mechanical cables, fairings, fishbite armor, and new surface buoys.

This paper first describes the surface buoy, a novel, hemispherical, tuned buoy which used marine aluminum for its structure and SURLYN foam for its hull. The buoy design stems from a semi-empirical study of hull motion conducted with the help of scale models in the Oregon State University wave tank. Two main requirements are satisfied by this prototype: 1) increased mooring and payload capacity, 2) reduced dynamic response to wave motion. The mooring design and components are next presented. The paper concludes with a description of the technique used for mooring deployment and servicing and a review of the results obtained so far.

112. Brown, Daniel M. Probabilities of Detection and Recognition of Flashing Lights on Rolling Buoys. U.S. Coast Guard Research and Development Center Report CG-D-10-88, Groton CT: August 1987.

This report shows how buoy motion affects a mariner's ability to detect and recognize standard Coast Guard buoy lights. Buoy roll reduces the effective intensity of the

light in the mariner's direction, which results in a detection distance much shorter than the currently used nominal range. Data for this analysis were provided by recording motion of two buoys with a specially designed optical device. The data were analyzed to predict variation of light intensity in a mariner's direction over time and, furhtermore, to predict probabilities of detecting and recognizing flash characteristics of the light. Results show increased detection range with increased vertical divergence, reduced detection range when buoy roll period and flash period are similar, and detection distances as short as 30% of published nominal range.

114. Colburn, W. E. "Wave Activated Turbine Generator (WATG) Buoy." Aids to Navigation Bulletin (Jun 1974-Jul 1975): 19-11.

This article presents some results of tests on a WATG buoy. The discussion includes information on power generation and consumption.

115. Engelhard Minerals & Chemicals Corp. Fuel Cell Batteries for Operation of Aids to Navigation. U.S. Coast Guard Research and Development Center Report No. CG-D-83-77, Groton, CT: 1977.

A program for the development of air-breathing fuel cell batteries for the operation of aids to navigation is discussed. Calcium hydride is used as fuel. The fuel cell batteries provide a significantly higher energy density than conventional power sources. The development focuses on a battery system suitable for U.S. Coast Guard requirements. Modules with a capacity of 6KWH and a nominal rating of 2 watts at 13 volts are being developed. Design and evaluation of single cells and battery modules are discussed. Testing is performed mostly with a U.S. Coast Guard flasher using a 1.15A lamp.

The program discussed in this report is a first step towards the development of hydride-based fuel cell batteries for use with aids to navigation. The development effort carried out so far has confirmed the suitability of the hydride cell for the design of high energy density batteries. Additional work is required in hardware areas.

116. Fisher, Wayne A. "Luminous vs. Nominal Ranges for Major Coast Guard Lights." The Coast Guard Engineer's Digest, COMDTPUB P5240.2, Vol. 24 No. 230 (Summer 1986).

This article presents an explanation of the difference between "nominal" and "luminous" range for an aid to navigation. A method is suggested for determining the spacing of major aids.

117. Glahe, P. J. "Simple Graphical Method to Select Buoy Moorings." Proceedings of the 10th IALA Conference (Paper 1.2.7) Tokyo: International Association of Lighthouse Authorities, 1980.

Traditionally, the length of chain used in the mooring of a particular buoy was selected by past experience and rules of thumb. Minimization of the watch circle radius was never routinely considered. A graphical method has been developed that allows for the selection of mooring chain lengths and sinker sizes that keeps the buoy on station and results in the minimum watch circle radius.

118. He, M; Chen, J.; Cai, L.; Xu, Y. "Experimental Study on Optimum Paramaters of a Large Wave-Energy-Powered Light Buoy." The Ocean Engineer Vol. 5, No. 4, (1987): 84-90.

According to the requirements of the client, two light buoy designs were experimentally studied. They have different diameters determined by calculation. Each design contains four parameters, namely, displacement, length of central pipe, chamber/nozzle ratio, and the height of the air chamber. After combination, 162 sub-designs can be obtained. It was proved that the design with displacement of 8 tons, buoy diameter of 3.6 m, central pipe length of 4 m, chamber/nozzle ratio of 200 and air chamber height of 2.5 m gives the best response. Its output exceeds the expected capacity and corresponds to the spectrum at an expected wave period of 3 seconds. Based on the experimental data, the effects of parameters and wave steepness on the output are discussed.

119. Heerlein, Warren. Maintenance and Operation of a Small Wind Generator in the Marine Environment. U.S. Coast Guard Research and Development Center Report No. CG-D-29-86, Groton CT: July 1986.

This report discusses the maintenance and operation of a wind turbine generator that has been undergoing tests as a source of energy for remote Coast Guard lighthouses. The report documents both the effects of operating the wind machine in the marine environment and the maintenance that it required. Design parameters and performance records of the generator are also available.

120. Heinz, Kurt J. "Exposed Location Buoy Equipment Brief." Aids To Navigation Bulletin Vol. 16 No. 2 (Jan/Mar 1987): 8-11.

This article reviews design objectives and equipment installed on Exposed Location Buoys (ELBs). Discussions of Wave Activated Turbine Generators (WATG) and the ANBESS package are also included.

121. Heinz, Kurt J. "Exposed Location Buoy Technical Update." Aids to Navigation Bulletin Vol. 15 No. 2 (Dec/Jan 1986): 31-32.

This article provides an account of some problems experienced with the first 9X35 LR Exposed Location Buoys deployed. The focus is mainly on payload mounting and wiring.

122. Hilliker, D. J.; Colburn, W. E.; Cutler, J. W. Coast Guard Evaluation of a Wave Activated Turbine Generator Buoy. U.S. Coast Guard Research and Development Center Report No. CG-D-84-77, Groton, CT: September, 1977.

Wave activated turbine generator buoys were tested at Chesapeake Light (14 miles off Cape Henry, Virginia) and in Boston Harbor. The buoys were instrumented to record cumulative power generated and later modified to record sea state as well as other variables pertinent to turbine operation. Results are presented as long-term power generation, power generation as a function of wave height and period, and transfer functions from spectral analysis of data.

123. Kery, S.M. "Severe Environment Surface Mooring (SESMOOR)." Oceans '89 Conference Record: Institute of Electrical and Electronics Engineers, 1989.

A Severe Environment Surface Mooring (SESMOOR) program has been initiated and pursued by the Woods Hole Oceanographic Institution to develop and demonstrate the capability to make long term meteorological and near surface oceanographic measurements in higher latitudes and areas where harsh environmental conditions prevail.

This paper describes the deviation from standard mooring design made both to the surface buoy and to the anchoring line, to ensure the survivability of the mooring and its instrumentation when deployed in extreme weather conditions. A review is then made of the mooring performance while on station, and of the condition of the components after recovery. Recommendations for the design of similar moorings concludes the paper.

125. McLeish, David B. "Is the Aid on Station? or Where is the Sinker?" Aids to Navigation Bulletin Vol. 15 No 2 (Dec/Jan 1985): 16-18.

This article deals primarily with verification of buoy position during deployment and recovery. Some concepts of watch circle calculation are also reviewed.

126. Millbach, Miles A. "Advanced Buoy Lighting Equipment - ABLE." The Coast Guard Engineer's Digest, COMDTPUB P5240.2, (Spring 1989).

This article is an overview of a project intended to develop and apply new technology to improve effectiveness,

efficiency, and cost of minor aid light signals. Problems with existing lighting equipment are addressed. The main focus is on payload rather than the buoy platform itself.

127. Motherway, D. L. and Walker, R. T. "Improvements in Jetted Buoy Anchors." Proceedings of the 10th IALA Conference, Tokyo: International Association of Lighthouse Authorities, 1980.

The USCG elmploys embedment anchors for the mooring of navigation buoys in some areas of the western rivers. Current techniques involve water jetting a truncated cone-shaped anchor into river bottoms where relatively soft sand and silt are present. This research investigated the potential of increased holding power by using a "keying" anchor. That is, an anchor which is inserted by water jet in a manner which presents the least resistance and then "keyed" into a position presenting maximum resistance. Model anchors which included standard cone and 4 additional non-conventional types were load tested in the laboratory. The anchors were evaluated for ease of jetting penetration, water volume needed for jetting and pullout resistance. Test data indicated that those anchors requiring least jetting fluid developed the greater pullout resistance. Full scale tests were conducted and proved that the new designs provide significantly greater holding power than the cone.

128. Motherway, D. L. Development, Test, and Evaluation of an Explosive Embedment Anchor for Use in the Mooring of Small Coast Guard Buoys. U.S. Coast Guard Research and Development Center Report No. CG-D-98-76, Groton, CT: June 1976.

This report examines an explosive embedment anchor with regard to its application as a mooring device for small Coast Guard buoys in sheltered or semi-exposed environments. It traces the development of this EEA (explosive embedment anchor) system from its inception to its ultimate disposition with regard to Coast Guard usage and provides the basis for documenting in summary form all Coast Guard efforts on the system.

129. Motherway, D. L.; Goddard, J. Lightweight Anchors for Small Buoys -- A State-of-the-Art Survey. U.S. Coast Guard Research and Development Center Report No. CGR/DC-16/75, Groton, CT: June, 1975.

This report examines the replacement of concrete sinkers with other anchor types to reduce the cost of operating the system of small navigational buoys. Sets of requirements are defined that identify the anchors suitable for use in several operating situations. A ranking system is described that gives each anchor a series of scores relating to its desirability in the various situations. The highest scoring anchors are discussed in terms of their potential

for improving the buoy mooring operation.

131. Rivers, Wayne. Aids-to-Navigation Radar Requirements. U.S. Coast Guard Applied Technology Division Report No. 1, aWshington, DC: 1971.

The specifications of a stereotype maritime radar are assembled from a concensus of currently deployed radars for use with models of radar performance to define desired radar properties of a new series of navigation buoys. Model elements considered include detection thresholds in noise and clutter backgrounds, diffraction and duct propagation modes near the sea surface, and shadowing by sea waves. Recommended buoy cross sections and estimates of detection ranges and probability of detection are given.

132. Ryba, J. S. and Naus, D. A. Laboratory Evaluation of Solar Power Units for Marine Aids to Navigation. U.S. Coast Guard Research and Development Center Interim Report CG-D-106-76, Groton, CT: 1976.

This report describes the Coast Guard evaluation of solar energy as a power source for lighted aids to navigation. Fifty-three solar powered aids, on test in a natural environment at Groton, Connecticut, have been continuously monitored for two years. Solar arrays from two manufacturers were tested with neither being wholly satisfactory. One had major quality control problems while the other suffered from inadequate sealing. Three types of lead-acid batteries used for energy storage have all been satisfactory to date. The test has indicated the advantages of voltage regulation in reducing water use in batteries, but has not proved that regulation is in fact required for long battery life. The insolation measured has shown excellent agreement with that predicted using averages from a surrogate area. Almost all of the original estimates that were made to predict system performance proved to be very conservative and most of the systems performed better.

133. Speckter, H. E. "A New Radar Reflector for Buoys and Other Aids to Navigation." Proceedings of the 10th IALA Conference Tokyo: International Association of Lighthouse Authorities, 1980.

Floating aids to navigation have long been equipped wtih radar reflectors to ensure safe and dependable radar navigation. For this purpose, a variety of reflector types have been developed and used over the years. However, measurements and theoretical considerations have shown that the majority of these reflectors yield unsatisfactory results. As part of a systematic study aimed at the optimization and standardization of radar reflectors for aids to navigation, a new reflector has been developed whose outstanding features include a large radar cross section, an almost omnidirectional back-scatter diagram, and a high

mechanical strength.

The paper describes the characteristics and application potential of the new reflector. In addition, it includes a review of radar performance and provides approximate required size and installation height.

135. Stramandi, Nicholas. Test and Evaluation of Lightweight Drag Type Anchors For Use with Small Coast Guard Buoys. U.S. Coast Guard Research and Development Center Report, Access No. 3158, Groton, CT: October 1977.

Results are presented of field tests and prototype deployments utilizing lightweight drag anchors to moor small Coast Guard Buoys. An empirical equation for calculating the holding capacity of selected lightweight drag anchors is developed as a function of anchor type, size, soil conditions, scope, type, and direction of load. The ability of the anchor to keep position and to be set on charted position plus the distance required to drag the anchor to set and its veering characteristics is investigated and used to develop a deployment procedure for small buoys. Additionally, hypothetical operational cases are presented to highlight potential benefits which could be expected through the use of these anchoring systems as opposed to concrete sinkers having equal holding power.

When deployed by the recommended procedures and sized by the design approach of this report, lightweight drag anchors can serve as anchors for small buoys.

136. Trenchard, S.E. Testing of Solar Photovoltaic Arrays for Utilization on Marine Aids to Navigation. U.S. Coast Guard Research and Development Center Report No. CG-D-10-81, Groton CT: 1981.

In 1978, approximately 400 solar photovoltaic arrays were procured and placed at marine exposure facilities in Groton, Connecticut, and Fort Lauderdale, Florida. The arrays were measured quarterly to ascertain the effects of the marine environment on electrical performance. Concurrently, a screening test for photovoltaic arrays to be used in the marine environment was developed at the Coast Guard R&D Center. Identical panels to those on test at the exposure sites were run through the pressure, immersion, and temperature (PIT) screening test. Based on the marine environment exposure test and the PIT screening test recommendations are made on the constituent materials and construction techniques of solar photovoltaic arrays that are most suited to use in the marine environment.

138. Way, J. G. "Synthetic Moors." Aids to Navigation Bulletin Vol. 18 No. 2 (Mar/Apr 1989): 19-20.

This article describes problems experienced in the handling of synthetic mooring lines while retrieving aids to navigation. The author suggests using foam floats

with chain moorings.

139. Whittaker, T. J.; McPeake, F. A.; and Barr, A. G. "Development and Testing of a Wave-Activated Navic tion Buoy with a Wells Turbine." Journal of Energy Resource 1 chnology Vol 107 No 2 (1985).

This paper presents and discusses the results of the first stage of an ongoing research program to improve the design of wave powered navigation aids using the oscillating water column principle. Wave tank testing has shown that the heave motion of current tail tube buoys is the predominant feature of the hydrodynamic response. A wells self rectifying air turbine, coupled to a 100-W generator which produces an optimum level of damping to the water column for peak performance, has been designed and tested. It has been concluded from preliminary sea trials that a simple, efficient, reliable, turbine-generator has been developed to meet the requirements of the current design of navigation buoy. However there is considerable scope for improving the hydrodynamic design of wave activated buoys.

140. Winslow, T. S., Mandler, M. B. Evaluation of the Hypothesis That Laser Light is More Conspicuous Than Incandescent Light. U.S. Coast Guard Research and Development Center Report No. CG-D-16-86, Groton CT: May 1986.

It has been thought that laser aids-to-navigation might appear more conspicuous than aids employing conventional light sources. Two experiments rigorously tested this theory. Incandescent and Helium-Neon laser sources were optically filtered and adjusted to the same illuminance and color to distant viewers. Observers viewed random presentations from a distance of 1500 yards both indoors and outdoors. It was concluded that at "practical" design illuminance levels, no significant conspicuity advantage would be gained by replaceing existing aids with laser aids. Calculations show a significant conspicuity advantage is likely if the mariner uses a narrow bandpass filter centered at the laser wavelength, thus diminishing background light illuminance. An additional section compares the electrical efficiency of a standard Coast Guard FA-240 range light with a laser.

141. Wyman, D. M. "Elastic Tethering Techniques for Surface and Near-Surface Buoy Systems." Oceans '82 Conference Record, Washington D.C.: Institute of Electrical and Electronics Engineers, September 1982.

The application of elastic tethering technology to the design of surface and near-surface buoy systems has resulted in improved data collection and high resolution navigation in the relatively shallow water covering the continental shelves. These elastic, taut buoy systems possess the ability to withstand the mechanical shock experienced as a

result of tide and wave forces. Continuous tension supplied by the compliant mooring array typically limits the horizontal excursion of the buoy to 5 to 10% of the water depth. This paper touches on the history of this technique from its development in the mid-1960's as data collection platforms to its present use with offshore benchmarks for hydrocarbon exploration. The results of selected programs in which this technique was used are discussed. Also discussed is the computer program, TAUT-MOOR, developed to predict mooring geometry and assist in effective system design. Suggestions for future applications are also introduced.

142. Armstrong, M. C. "Experience With Three Buoy Designs in Aluminum Alloy." Proceedings of the 10th IALA Conference, Tokyo: International Association of Lighthouse Authorities 1980.

In recent years Canada has had to produce three buoy designs where lightness was the prime operational requirement. Reasons are given for the selection of aluminum. The duty requirements and designs of each buoy are described and results of model and field testing are given. Operational experience to date is presented and general recommendations are given regarding the use of aluminum for buoys.

143. Berteaux, H.O.; Bocconcelli, A.; Gould, M.; Kery, S. Testing and Evaluation of SURLYN Foam and SPECTRA Fiber Ropes for Buoy Systems Applications. Woods Hole Oceanographic Institute Report WHOI-88-32, Woods Hole, MA: 1988.

Softlite foam offers many advantages as buoyancy material for surface buoys because of the foam's following characteristics: low weight/volume ratio; tough material which is resistant to the marine environment; no painting needed since pigment is melted into the plastic during the manufacturing process. The test results indicated that more factors besides density must be taken into consideration when choosing the right foam for a specific application. In the case of a surface buoy, some very important parameters are: surface area to volume ratio; number of concentrical layers of foam wound up to form the main body; outer skin conditions.

144. Booz-Allen Applied Research, Inc. "Evaluation of Plastic vs. Steel for Buoy Hulls." Unpublished Report for U.S. Coast Guard Headquarters, Contract No. DOT-CG-90506-A, Washington, DC: 1970.

The purpose of this report is to evaluate the technical, operational, and economic feasibility of plastics for use as buoy hulls for aids to navigation. The study began with a review of existing technical data on plastics, interviews with key personnel in the Coast Guard, and observations of buoy operations and sea tests on plastic buoys. Based on this information, an evaluation of the technical and operational feasibility of plastics was made, and a life cycle cost analysis was performed.

The conclusions of the study are: plastic buoys can be as or more effective than steel buoys; plastic hulls can be developed for all environments except heavy ice; maintenance costs would be less for plastic hulls; total annual costs for plastic hulls are comparable to steel hulls; servicing vessel size could be reduced by using plastic buoys.

The report recommends the use of plastics for USCG buoy

hulls and a special group be formed to oversee development.

145. Boy, R. L. and Chang, R. K. "Foam Buoy Retro-Reflective Material." Aids to Navigation Bulletin Vol. 18 No. 1 (Jan/Feb 1989): 15.
This article presents an evaluation of two new retro-reflective materials and adhesives for foam buoys.

146. Brown, R. R. and Kohler, C. A. Corrosive Wear of Buoy Chain. U.S. Coast Guard Research and Development Center Report No. CG-D-17-88, Groton, CT: 1988.
Five alloy steel chains were exposed to a service environment as buoy chains to determine the best candidate to replace the 1022 steel currently used. The best combination of resistance to material loss, strength, and pitting corrosion resistance was shown by the 4340 quenched and tempered steel. In the chafe section, the 4340 steel displayed the best resistance to wear even thought it was located in rocks and sand. The 1022 steel performed the best in terms of overall weight loss; however, the chain was positioned on a sandy location and showed greater wear in the chafe section. These results suggest that the 4340 steel may be an alternative to the 1022 steel in areas where the chain moorings experience rapid corrosive wear. However, the availability and weldability of the 4340 steel make it unsuitable as a buoy chain material at the present time.

147. Campbell, W. J. "Aberglen Seamarks Range of GRP Buoys Size 1.2 Metre to 8 Metre Diameter." Proceedings of the 10th IALA Conference, (Paper 3.1.13), Tokyo: International Association of Lighthouse Authorities, 1980.
This report describes the new range of Aberglen Seamarks GRP buoys in sizes ranging from 1.2 meters to 8 meters in diameter and explains the advantage of GRP as a material for buoy construction.

148. Chang, R. K. "Update on Foam Buoys." Aids to Navigation Bulletin Vol. 17 No. 2 (Mar/Apr 1988): 14-15.
This article is a review of developments and problems with regard to foam buoys. The article includes designations and weights of those buoys available at the time of publication.

149. Dowd, Theodore. "No Foul Anti-fouling Rubber Coating For Buoys." Proceedings of the 10th IALA Conference (Paper 3.1.9) Tokyo: International Association of Lighthouse Authorities, 1980.
A buoy coated with "No-Foul" rubber (chloroprene impregnated with 8 percent TBTO) was deployed on station for 11-1/2 years. During this period the buoy was protected from corrosion and resisted the formation of extensive fouling. However, the coating did not prove cost effective in the

long run.

150. Drisko, Richard W. Plastic Mooring Buoys - Part II. Completion of Test Program. U.S. Naval Civil Engineering Laboratory Report No. R601, Port Hueneme, CA: 1968.

Two plastic mooring buoys, fabricated by a private contractor,were described in part I of this study. Each buoy had a steel framework filled with closed-cell polyurethane foam. On one buoy this foamed core was covered with a shell of fiberglass cloth impregnated with polyester resin; on the other, the shell was a sprayed-on coating of chopped fiberglass strands in polyester resin.

This report describes the 3-year in-service testing of these buoys in San Diego Bay. While both performed well, the hand lay-up buoy had much less deterioration than the spray-up buoy. Also, it was determined that plastic buoys have much lower maintenance costs than steel mooring buoys.

An improved plastic mooring buoy was designed from the results of the testing program. This design utilizes hand lay-up construction of the outer shell with alternate layers of chopped-glass mat and woven roving. Such a buoy is currently serving the Fleet at Pearl Harbor, Hawaii.

152. Fuller, R. G.; Nowacki, L.; Brand, B.; Fink, F.W.; Boyd W.K. Prevention of Deterioration of Navigational Buoys. Battelle Memorial Institute, NTIS Access No. AD786327, Columbus OH: 1963.

This report reviews in detail (1) the factors which influence buoy service life and (2) the present Coast Guard maintenance procedures. The consensus is that the currently specified vinyl coating system is excellent. However, suggestions are advanced for possible means of improving the anticorrosive and antifouling paints. In addition, suggestions are presented regarding the use of alternative materials of construction.

153. Glahe, P. J. "History of the Development of Plastic Buoys by the United States Coast Guard." Proceedings of the 10th IALA Conference (Paper 3.1.5) Tokyo: International Association of Lighthouse Authorities, 1980.

This paper traces the development, design, and testing of six plastic buoys over a 12 year period. Buoys of FRP, ABS, and Cross-linked Polyethylene are described and successes as well as failures are outlined. Test results indicate that while significant reductions in the weight of large buoys can be achieved by the use of plastic materials, the life of the buoy is significantly reduced. Often these large buoys are much more expensive than associated steel buoys. On the other hand, the use of plastic materials in small buoys has resulted in significant weight reduction and cost savings. The future outlook for the use of plastics in large buoys is also presented.

154. Glahe, P. J. Design, Procurement, and Testing of Plastic Fast-Water Buoys on the Arkansas River. U.S. Coast Guard Ocean Engineering Division Technical Report, Access No. 2494, Washington, DC: March 1976.

This report describes the design, procurement, and testing of plastic fast-water buoys on the Arkansas River. The final design incorporated a segment of a spherical hull shape and a rotationally molded plastic exterior. Testing showed that the buoy had to be self-righting in all current and mooring conditions. The 250 test buoys were modified with varying counterweights. Their maximum current riding ability is about 5-1/2 kts, with a total submergence well above this level. Certain structural problems can be corrected by design modification and better quality control.

156. Littauer, E. L. "Cathodic Protection of Buoys and Offshore Structures." Transactions of the 1964 Buoy Technology Symposium, Washington, D.C.: Marine Technology Society, March, 1964.

The paper discusses briefly the theory of corrosion of iron in sea water and fresh water. Emphasis is made on the significance of micro and macro areas on metal surfaces potentials which create anodic/cathodic corrosion cells. A simplified theoretical explanation of cathodic protection is given. An outline of how this type of protection can be applied specifically to buoys and structures is given, and the consequences of over protection are discussed. The corrosion problems pertaining to buoys and offshore structures are discussed and methods of corrosion prevention described. The current requirements for protection are outlined. Experience to date has shown that successful protection can be achieved on completely bare steel surfaces at a very low cost and, in fact, life expectancy can be extended for as long a time as cathodic protection is installed.

157. Mandler, M. B. Detection and Identification of Flourescent and Non-Flourescent Daymark Materials. U.S. Coast Guard Research and Development Center Report CG-D-05-88, Groton, CT: August 1987.

Detection and color identification distances of flourescent and non-flourescent chromatic materials were measured to compare performance of these two types of materials for use on daymarks. New flourescent materials had greater detection and identification distances than most non-flourescent materials due to their ability to convert ultraviolet light to visible light. As flourescent materials age, they become more difficult to detect and identify. With one exception, non-flourescent materials could be detected and identified at greater distances than the aged flourescent materials. This report also examined the

relationship between luminous contrast and Munsell notation on detection and identification distances. Detection distance was positively correlated with luminous contrast and Munsel Value. Munsell Chroma was not a good predictor of detection or identification distance.

158. Pike, Dag "Plastic Buoys." The Dock and Harbour Authority, (Feb 1980).

The two main reasons for using GRP for buoys are that GRP is readily adaptable to the complex shapes required for some buoy designs and that it should have a longer and more maintenance-free life because of its corrosion resistance. The considerable reluctance to change to GRP buoys by many buoyage authorities lies in the early development of GRP buoys, in difficulties of making a smooth change over in construction materials, and in inherent disadvantages of GRP as a material when compared with steel. The Italian firm of Resinex produces a wide range of buoys which incorporate a galvanized steel structure to provide strength and a closed cell polyvinyl chloride foam to provide buoyancy. The concept of a resilient buoyancy chamber greatly reduces the chances of collision damage. The dilemma facing buoyage authorities is the cost of the Resinex buoys, which is higher than GRP or steel.

164. Tindle, E. R. "Steel vs. GRP Buoys - An Analysis After Several Years Experience." Proceedings of the 10th IALA Conference (Paper 3.1.6), Tokyo: International Association of Lighthouse Authorities, 1980.

The 1965 Conference General Report 3-1 predicted a great future for the use of "plastic" materials in large buoys. The expected revolution in the acceptance of these materials, however, has not been realized. This report is an attempt to analyze the failure of "plastic" to meet expectations.

166. Bech, A. and Leira, B. J. Effects of Load Modelling on Dynamic Response: Articulated Tower. NTNF Research Project Report No. 4.2, Netherlands: 1984.

This report details the effects of using actual versus static positions as a basis for wave force calculations. An articulated tower has been studied, both by means of simplified analytical considerations and a numerical computer program.

It is concluded that the effects of using instantaneous positions may be significant considering both load and response. Total wave load moments about the joint, displacements, and internal moments in the tower are extracted from the analysis.

167. Berteaux, H. O. and Boy, R. L. "Wave Tank Study of Moored Buoy Hulls for Air-Sea Interaction Applications." Oceans '86 Conference Record: Institute of Electrical and Electronics Engineers, 1986.

Measurements of atmospheric and oceanic parameters for air-sea interaction studies are made from deep sea moored surface buoys. Tests have been recently conducted at the Wave Research Facility of the Oregon State University to observe the response of moored buoys and assess the impact of buoy shape and mooring attachment on the motion of the sensors. This paper presents the rationales for the selection of the hull shapes, and the considerations for scaling and modelling the buoys. A novel approach for modelling the mooring line is explained. A review is made of the data acquisition and processing techniques. A summary of the test results concludes the paper.

168. Bitting, K. R. Computer Mooring Simulation of a Rubber Band Mooring on an 8x26 Navigational Buoy and an 8-Foot Diameter OSI Buoy. U.S. Coast Guard Research and Development Center Report No. CGR/DC-29-75, Groton, CT: 1975.

The computer simulation was performed on a rubber band mooring to estimate the extent to which that mooring method can reduce the watch circle of a navigational buoy. An 8x26 navigational buoy and an 8-ft diameter OSI buoy were used in the mooring simulation. The 8X26 is used because it is presently in the AtoN system. The OSI buoy was used because it is a low-drag, lightweight plastic buoy that may be used in place of the 8x26. The rubber band mooring is compared to a one-inch diameter nylon mooring. The rubber band mooring can reduce the watch circle of both buoys when compared to the slack nylon mooring. This reduction is most apparent at low currents (approx. 1 kt.) and becomes less pronounced as the current approaches 3 knots. The OSI buoy shows a smaller watch circle than the 8x26 due to its low drag. While the rubber band mooring increases the mooring tension, it does not increase the sinker weight over that for a chain

mooring. Increasing pretension reduces the watch circle.

169. Bose, K. R. and Rao, E. V. "Development Of A Theory For The Analysis Of Articulated Bottom Fixed Beacons For Use As Offshore Light Structures." IALA Bulletin No. 79 (1979/3).

Articulated beacons hinged at the sea bed are being considered by several lighthouse authorities as light structures for offshore locations, particularly where the currents are not very strong and the other environmental considerations are not too severe.

A theory has been developed for the analysis of the movement of such structures under the combined action of wind, waves, and currents, all assumed to act in the same direction.

A computer program based on this theory has been used to predict the behavior of such a beacon at different locations with varying environmental conditions and it confirmed the validity of the computation.

170. Carson, R. M. "On the Capsize Performance of a Discus Buoy in Deep Sea Breakers." Ocean Engineering Vol. 9 No. 5 (1982).

The mode of capsize of a discus buoy in breaking waves is discussed. The results of model tests are given; these show that a judicious choice of mooring design can substantially reduce the chance of capsize. A comparison is made with the performance of the buoy on station.

171. Cavaleri, L. and Christensen, E. M. "Wave Response of a Spar Buoy With and Without a Damping Plate." Ocean Engineering, Vol. 8 No. 1 (1981).

This article is a report on a computer analysis of wave response of a spar buoy that has been operated successfully in the Mediterranean over the past ten years, to find out how the presence of a large horizontal plate at the bottom affects its wave response. The calculations show that the addition of a damping plate decreases wave response for short waves, but increasea the response for very long waves.

172. Chapman, P. O. Tests of 8X26 BE(RR) Buoy, 1962 Design. U.S. Coast Guard Field Test and Development Unit Project, Report No. CGTD J24-2/1-1-29, Washington, DC: 1962.

The performance of a new design ocean-type lighted buoy is compared to the present standard buoy. Such factors as acoustical performance of the bell, period and amplitude of roll, and natural vibration resonances were investigated. The radar and visual range of the two buoys were also compared as well as ease of handling.

173. Chou, F. S. "Minimization Scheme for the Motions And Forces of an Ocean Platform in Random Seas." SNAME Transactions Vol. 85: Society of Naval Architects and Marine Engineers, 1977.

An analytical procedure for the optimal design of a vertical float-supported ocean platform, as derived from minimizing its motion in rough seas, is considered in this paper. The method of calculus of variations, together with the penalty function method, is used to determine a set of necessary conditions from which an integral equation is obtained for the volume distribution which minimizes the platform's motion in a random sea. The ITTC wave spectral density function is used to simulate real sea conditions. A previously tested buoy and platform are used as standards, and an optimal buoy and optimal platform with the same major characteristics are derived numerically. A significant reduction in significant heave amplitude for higher sea states is observed for the optimum buoy and platform. It is concluded that this technique is useful in preventing unwanted excessive motions of a platform in random seas. The basic approach can be adapted to a wide class of shapes.

175. Cox, J. V. STATMOOR - A Single-Point Mooring Static Analysis Program. Naval Civil Engineering Laboratory report, Acc. No. AD-A119979, June, 1982.

STATMOOR is a static mooring analysis program written in BASIC language and is one program in a hierarchy ofprograms developed at the Naval Civil Engineering Laboratory for mooring analysis. STATMOOR analyzes the static response of a single-point moored vessel and hawser. The menu arrangement of the program lends itself to a user-oriented conversational mode. The user has the option to enter, review, edit input, and obtain calculated results in printed tabular, video graphics form. Steady current, wind, and wave loads are considered. Wind load estimates are considered to be as accurate as the knowledge of the wind environment; current and wave loads are in a preliminary form and merit further refinement. STATMOOR was written to demonstrate the utility and ease of use of conversational mode programs and the potential for programs to replace design manuals.

176. DeBok, D. H. and Roehrig, S. F. "Numerical Modelling of Coast Guard Buoys in Shallow Water." Oceans '81 Conference Record, Boston, MA: Institute of Electrical and Electronics Engineers, 1981.

This paper describes recent attempts by the Coast Guard R&D Center to analyze the dynamics of typical Coast Guard buoys moored with synthetic line in shallow water, using an existing numerical model. Large-scale model wave tank tests have shown that the weight and drag of the synthetic line are negligible when compared to the tension forces, so that

the catenary effects may be ignored. This allows the use of a single linear segment in the modelling of the mooring line, thus eliminating numerical convergence problems commonly experienced in time-domain simulation of shallow water dynamics. A unique system for measuring buoy position in wave tank tests is discussed. The procedure for extracting buoy hydrodynamic coefficients from wave tank data is outlined, along with the current capabilities of the numerical model to estimate mooring line tensions and buoy attitudes in various wave conditions.

177. Dynamic Analysis of the PIXIE Buoy for Project Linear Chair. United States Navy CHES/NAVFAC Report No. FPO-1-77(28) (Available through the Defense Technical Information Center).

The PIXIE buoy has been chosen as the initial platform for acquiring airborne magnetic, electric, and electromagnetic measurements during the preliminary sea trials of the Linear Chair system in FY80. A mooring system must be developed that will minimize buoy motion responses in both shallow (100 to 200 feet) and deep (2000 to 3000 feet) water configurations. The following analytical data are illustrative of a technique to predict and evaluate the expected responses of the PIXIE buoy under various sea conditions and mooring configurations. These equations and graphs are meant as an aid to the investigator in designing the optimum mooring configuration for the buoy with regard to allowable motion and tilt as determined by the sensitivity of the buoy-mounted instruments. Actual numerical values presented are only illustrative as they do not reflect the actual configuration of the PIXIE buoy.

179. Garrison, C. J. "Hydrodynamics of Large Objects in the Sea Part I - Hydrodynamic Analysis." Journal of Hydronautics Vol. 8 No. 1 (Jan 1974).

This paper deals with the hydrodynamic forces exerted on a rigid object describing harmonic oscillations under or on a free surface as well as the forces resulting from the interaction of the object held fixed in a train of regular surface waves. The problem is formulated for a body of arbitrary shape in water of finite depth and the development of a numerical scheme for carrying out the calculations is described. An energy balance as well as Haskind's relation are used as a check on the accuracy of the numerical results. Numerical results are presented for a floating sphere, a vertical circular cylinder, and a practical semi-immersed caisson configuration.

181. Hoffman, Dan; Geller, E. S.; and Niederman, C. S. "Mathematical Simulation and Model Tests in the Design of Data Buoys." SNAME Transactions Vol. 81: Society of Naval Architects and Marine Engineers, 1973.

Data buoys are now being deployed by NOAA and NDBO as part of the marine environmental reporting network. This paper discusses the design of these buoys as small ocean platforms. To predict short-term buoy performance, under a given set of environmental conditions, a hull and mooring simulation is developed as a three degree of freedom, vertical plane, frequency domain mathematical model. The steady-state response to wind and current is perturbed to obtain the performance in waves. The simulation has been validated by scale model tests, which demonstrated its adequacy for buoy design. The model test results are also used to predict full-scale buoy performance. The statistical technique used to forcast long-term performance at any ocean deployment site is described. Plans are presented for full-scale ocean tests to verify the simulation and model test results.

182. Kerr, K. P. "Stability Characteristics of Various Buoy Configurations." Transactions of the 1964 Buoy Technology Symposium, Washington D.C.: Marine Technology Society, March 1964.

A summary of information on stabilization and floatation devices obtained from theoretical analyses and model testing is presented. The results are related to the hydrodynamic stability of buoys, ranging in size from large manned oceanographic stations to small sonobuoy configurations. Wave induced heave and pitch motions for a long slender buoy as determined theoretically and experimentally are compared, and a method to predict vehicle response in a confused dea is presented. Cases where buoy resonance conditions are easily excited by average wave motion can be corrected by (1) adding a horizontal damping plate at the base to minimize heave and heave-induced pitching motions, or (2) using a large floatation device to assure buoy in-phase vertical motion with the waves to keep the waterline constant. The required floatation device and/or heave damping plate to effect stability depends on buoy size, mass distribution, and sea environment.

183. Marine Technology Systems. Buoy Hull and Mooring Model Applications Study Final Report. U.S. Coast Guard Contract DOT-CG-33362A: Sperry Rand Corporation, 1974.

The United States Coast Guard (USCG) is currently developing prototype aid-to-navigation buoys to replace existing standard buoys. The introduction of plastics with anticipated reduced maintenance and operating costs, as well as the possible replacement of over-age buoy tender vessels has stimulated the development and evaluation of new buoy

designs.

The Buoy Hull and Mooring Applications Study has been undertaken to provide the USCG with the capability of evaluating, through the application of a comprehensive mathematical model, existing prototype designs as well as proposed new designs. As a first step in achieving this objective an existing hull and mooring dynamic model has been expanded and applied, on a limited basis, to the evaluation of existing and proposed aid to navigation designs.

186. Measurement of Floating Buoy Movement." The Coast Guard Engineer's Digest, COMDTPUB P5240.2, Vol. 21 No. 213 (Winter 1982).

This article presents an overview of a system for tracking buoy motions utilizing a TV camera and a computer processor which digitizes images from light sources mounted on the buoy. The system is still under development.

187. Mooring System Design and Time Domain Simulation of a Semisubmersible Buoy. Watt Associates, Inc., Report NTIS Access No. AD-A163 490: 1983.

The goal of this task is to determine the steady-state dynamic mooring forces for a three-leg semisubmersible buoy, moored in depths ranging from 100 to 400 feet, and being subjected to the survival wind, current, and wave for the site. The dynamic response of the moored semisubmersible to the survival environment will be simulated using Computer-Aided Design techniques.

188. Moukawsher, E. J. "Self-Righting Characteristics of Fast Water Buoys." U.S. Coast Guard MAP Project Report (unpublished), 1976.

The self-righting characteristics of the Coast Guard's experimental lightweight fast water buoys are evaluated from field measurements.

The tests were conducted in order to obtain graphs describing the self-righting ability of the buoys as a function of scope and current speed for both NUN and CAN shaped daymarks.

A separate test was conducted to determine whether the buoys would self-right with the daymark flooded if four one-inch holes were drilled into the tops of the daymarks.

189. Multer, J. and Smith, M. W. Aids to Navigation Radar I Experiment Principal Findings: Performance in Limited Visibility of Short Range Aids with Passive Reflectors. Eclectech Associates report to U.S. Coast Guard Headquarters, No. CG-D-79-83, Washington D.C.: Dec 1983.

This report describes an experiment conducted as a component of the U.S. Coast Guard's Performance of Aids to Navigation Project. The experiment evaluates the efficacy of

floating aids (buoys) equipped with passive reflectors and the use of radar (3 cm) in a limited visibility. The following variables were evaluated: visibility, ship size, buoy arrangement, wind, and current. In additon, comparisons to previous experiments in this project were made to evaluate differencesbetween piloting with radar in low visibility and in adequate visibility without radar.

Differences in performance were most evident in the turn region while differences in the trackkeeping region were less noticable. Performance in the turn region suffered more in the low visibility conditions with radar. Pilots performed better with a smaller ship and with aid arrangements having a higher density spacing. Finally, style differences in radar use affected ship track performance.

190. Nath, J. H; Chester, S. T.; Bunney, R. E.; Brooks, D. M. "Discus Buoy Stability and the Spectrum of Steep Waves." Journal of Ship Research Vol. 24 No. 3 (Sept. 1980).

Thick discus buoys are used in the ocean as platforms from which oceanographic and meteorological measurements are made and reported to shore. The stability of these buoys is sensitive to steep breaking waves, and a few have capsized in the ocean from large breaking waves. This occurence can be simulated in laboratory scale-model studies. This paper describes how first approximations can be made from a combination of laboratory scale-model testing of buoy capsizing in random waves, a few reported occurences of buoy capsizings in the open ocean, and the statistics of ocean waves. An estimate of the joint probability density distribution of a wave steepness parameter and a wave height parameter is made from buoy motion measurements.

191. National Data Buoy Center. Users Guide and Operations Manual for Static Stability Program. Bay St. Louis,MS: National Data Buoy Center, March 1988.

This document is a users manual for a computer program developed at the National Data Buoy Center. The program calculates hydrostatics, weight, and stability data for various buoy hulls, including the NOMAD and 12 meter buoys.

192. Pattison, John H. Hydrodynamic Drag of Some Candidate Surface Floats for Sonobuoy Applications. Naval Ship Research and Development Center Report 3735, Carderock, MD: 1972.

This report explores the hydrodynamic characteristics of several candidate surface floats for application to the Naval Air Systems Command Advanced Acoustic Search Sensors Program. It is desirable to find surface floats with low drag-to-displacement ratios which are hydrodynamically stable. Three contractors supplied models for experiments which were conducted in the circulating water channel facility of the Naval Ship Research and Development Center.

The models were spheres, spheres with cylinders attached, spheres with cylinders and fairings attached, an ellipsoid, a hemisphere, and a disk. Drag and stability results obtained for these models are compared on the basis of drag-to-displacement ratio, vertical force-to-displacement ratio, Froude number based on float diameter, sway amplitude-to diameter ratio, and surge amplitude-to-diameter ratio. The hemisphere and the disk had the lowest drag and the best stability characteristics.

193. Pearlman, Michael D. "Consideration for the Optimization of Particular Characteristics of Stable Buoys." Transactions of the 1964 Buoy Technology Conference, Washington, D.C.: Marine Technology Society, March 1964.

For many years a large number of radically different buoys have been anchored at sea to provide platforms for various oceanographic studies. For a large number of these studies it is desirable to provide a buoy whose motions due to seas can be minimized. This paper describes the equations of motion for a particular buoy configuration and its mooring system.

Given a particular task which must be carried out at sea the desired characteristics of the support platform (buoy) can be specified to facilitate the operation. A buoy and mooring configuration can then be chosen and the combination can be studied as a system to optimize the desired characteristics.

195. Price, David. "Buoy Response Amplitude Operators Obtained From Step Response Tests." The 8th Annual Offshore Technology Conference Proceedings, Houston Tx: May 1976.

Response Amplitude Operators (RAOs) are obtained by the application of existing theory to measurements of the transient response of a buoy to steps of heave and angular displacement. These results are compared with RAOs computed from sea and motion spectra of two buoys of the same type deployed in an exposed sea location. Excellent correlation has been obtained between the two methods. With this validation, the expeditious step response technique can be applied with confidence to the comparative evaluation of buoy designs and other applications that involve the prediction of buoy motion.

196. Sanders, Philip M. "Development of a Digital Computer Algorithm to Model and Predict the Performance of Buoy Hull Form Designs for Use in Fast Water Conditions and Subject to Debris Accumulation." USCG Academy Scholars Project Report (unpublished), New London, CT: U.S. Coast Guard Academy, 1974.

Buoyage of rivers with fast current conditions, (four knots and above) and with large amounts of debris flowing downstream, is a major problem for the U. S. Coast Guard

while carrying out the Aids to Navigation Mission. This project is designed to lay the foundations of a research effort to develop a buoy capable of providing an adequate aid to navigation to mariners in areas where fast water and large amounts of debris exist. As a first step in such research a digital computer was used to model the buoy system under the influence of actually observed environmental conditions of fast current and debris accumulation on a buoy. A computer program was developed to specifically take inputs of a proposed buoy hull design and to predict how that proposed buoy hull design will be affected by existing environmental factors.

197. Scheiber, Donald J. Experimental Determination of the Hydrodynamic Coefficients of Surface Floats. Magnavox ASW Operations Division Report MK Tr-6-3-2000-70: The Magnavox Corporation, 1970.

This report presents the experimentally derived values for the hydrodynamic drag and lift forces acting on partially submerged surface floats in various currents. These parameters were measured over a range of Reynold's number from 0.5E06 to 1.4E06 and a range of Froude numbers between 0.2 and 0.9. Data is presented giving the drag and lift forces acting on spheres whose diameters were 27.75 in. and 26 in. in flows of 1.5, 2.25, 3, 3.5, and 4 kts. Other geometries studied included spheres with cylindrical attachments on their lower surfaces. The most interesting feature of the results is the appearance of a negative dynamic lift at submergence ratios between 0.5 and 1.0, particularly at higher velocities. The magnitude of the negative lift is sometimes greater than the drag term. At smaller submergence ratios, the lift appears positive indicating that such bodies can be used as efficient float geometries provided low submergences are utilized.

198. Smith, M. W. and Bertsche, W. R. Aids to Navigation Principal Findings on the CAORF Experiment - The Performance of Visual Aids to Navigation as Evaluated by Simulation. Eclectech Associates report to U.S. Coast Guard Office of Research and Development, No. CG-D-51-81, Feb 1981.

The experiment described in the present report is the first of a series done for the U.S. Coast Guard to quantify the relationship between variables related to aids to navigation and piloting performance in narrow channels. The present experiment was restricted to visual piloting, and, further, to buoys only. It was done at CAORF, the Maritime Administration's Computer Aided Operations Research Facility in Kings point, NY. The variables evaluated were: straight channel marking (staggered vs. gated buoys), spacing (5/8 vs. 1-1/4 nm), turnmarking (one vs. three buoys), day/night detection range (3/4 vs. 1-1/2 nm), angle of turn (15 vs. 35 degrees), and turn radius (noncutoff vs. cutoff). A scenario

was planned to include both trackkeeping and maneuvering tasks done both with and without perturbation. The findings are presented as the means and standard deviations of the crosstrack position of transits under each condition. They are interpreted as to effect on channel design and piloting.

201. Tucker, M. J. "Heave Response of a Spar Buoy." Ocean Engineering Vol. 9 No. 3 (1982).

The vertical response of spar buoys to waves is examined. The response is the product of a rather complex wave forcing function and the resonant response of the buoy. With compound spar buoys (that is, consisting of more than one section of different diameters) the forcing function has a zero at a frequency which is usually close to the resonant frequency, but can be arranged to be somewhat higher with beneficial effect on the response. Only the effect of pressure and inertia are considered, since this paper is mainly concerned with clarifying some specific general principles and it is difficult to include the effects of drag, which are complex.

203. Watanabe, A.; Shimizu, T.; Horikawa, K. "Response of a Moored Cylindrical Buoy to Irregular Waves. Coastal Engineering of Japan, Vol 24, p. 262 (1981).

The random wave response of a cylindrical buoy was investigated based on experimental data and numerical simulation. The simulation by the simplified equation of buoy motion was found useful. A simple practical method of buoy response prediction by using the representative wave height was proposed.